



Defense Acquisition Research Journal

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The Challenge of Defense Acquisition:

Getting it **RIGHT**,
Right from the
START



October 2015 Vol. 22 No. 4 | **ISSUE 75**

*Establishing the Technical Foundation:
Materiel Solution Analysis Is More Than
Selecting an Alternative*

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Lt Col William A. Riski, USAF (Ret.)**

*Requirements Engineering in an Agile Software
Development Environment*

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of Incompressibility in Comparing Learning
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*Balancing Incentives and Risks in Performance-
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*Forged in War: The Naval-Industrial Complex and
American Submarine Construction, 1940–1961*

Written by Gary E. Weir

Reviewed by Stafford A. Ward

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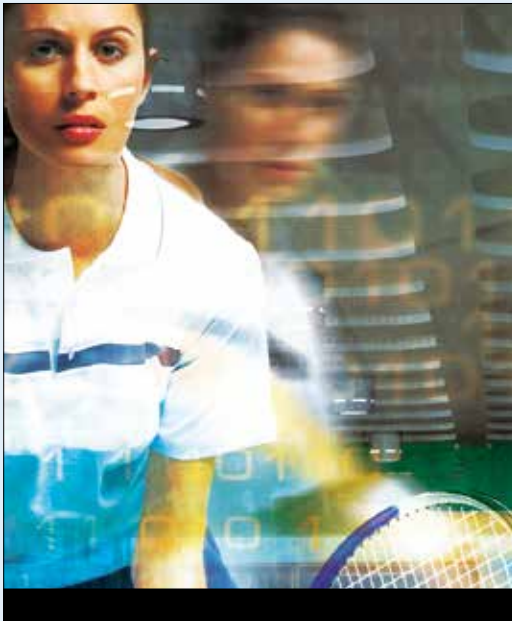


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Establishing the Technical Foundation: Materiel Solution Analysis Is More Than Selecting an Alternative

*Aileen G. Sedmak, Zachary S. Taylor, and
Lt Col William A. Riski, USAF (Ret.)*

Adequately resourced systems engineering and technical planning before Milestone A can help a program define realistic requirements, establish executable programs, and deliver systems on time and on budget.



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Requirements Engineering in an Agile Software Development Environment

W. Allen Huckabee

The use of best business practices and lessons learned to standardize requirements development and refinement processes can be beneficial to a Business Capability Lifecycle software acquisition program.

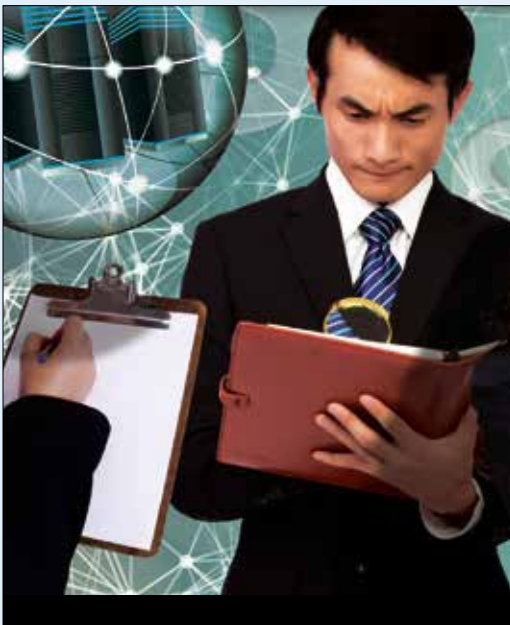


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Professional Reading List

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The Defense Acquisition Research Journal is a scholarly peer-reviewed journal published by the Defense Acquisition University. All submissions receive a blind review to ensure impartial evaluation.

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Defense ARJ Survey

We want to know what you think about the content published in the *Defense Acquisition Research Journal*.



CALL FOR AUTHORS

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GROUND RULES

- The competition is open to anyone interested in the DoD acquisition system and is not limited to government or contractor personnel.
- Employees of the federal government (including military personnel) are encouraged to compete and are eligible for cash awards unless the paper was researched or written as part of the employee's official duties or was done on government time. If the research effort is performed as part of official duties or on government time, the employee is eligible for a non-cash prize, i.e., certificate and donation of cash prize to a Combined Federal Campaign registered charity of winner's choice.
- First prize is \$1,000. Second prize is \$500.
- The format of the paper must be in accordance with guidelines for articles submitted for the *Defense Acquisition Research Journal*.
- Papers are to be submitted to the DAU Director of Research: research@dau.mil.
- Papers will be evaluated by a panel selected by the DAUAA Board of Directors and the DAU Director of Research.
- Award winners will present their papers at the DAU Acquisition Community Training Symposium, Tuesday, April 12, 2016, at the DAU Fort Belvoir campus.
- Papers must be submitted by December 16, 2015, and awards will be announced in January 2016.



FROM THE CHAIRMAN AND EXECUTIVE EDITOR

Dr. Larrie D. Ferreiro



The theme for this edition of *Defense Acquisition Research Journal*, “The Challenge of Defense Acquisition: Getting it Right, Right from the Start,” is addressed by a particularly strong lineup of articles. The lead article is “Establishing the Technical Foundation: Materiel Solution Analysis Is More Than Selecting an Alternative,” by Aileen G. Sedmak, Zachary S. Taylor, and William A. Riski. The authors describe the

research conducted under the Department of Defense Development Planning Working Group, which establishes the systems engineering and technical planning activities needed prior to Milestone A in order to develop realistic cost, schedule, and performance estimates. The second article, W. Allen Huckabee’s “Requirements Engineering in an Agile Software Development Environment,” explains how the agile environment used to create defense business systems today is not properly served by function-based requirements development. Instead, the author finds that user-story and acceptance methods are better adapted to establishing and updating system requirements.

In the third article, “Acquisition Challenge: The Importance of Incompressibility in Comparing Learning Curve Models,” authors Justin R. Moore, John J. Elshaw, Adedeji B. Badiru, and Jonathan D. Ritschel, find that the Wright’s Learning Curve model, now in use for over 75 years, does not accurately predict learning performance

compared with other, more recent models. In particular, the authors find that the effect of automation (“incompressibility”) plays a major factor in the accuracy of learning curve estimates. Nicholas J. Ross, in the final print article, “Technical Data Packages: When Can They Reduce Costs for the Department of Defense?” examines when and under what circumstances the government would benefit from buying a Technical Data Package (TDP) as part of an overall bid. He notes that buying a TDP does not automatically lead to savings from competition.

A fifth article, available in the online edition of *Defense ARJ*, “Balancing Incentives and Risks in Performance-Based Contracts,” by Christopher P. Gardner, Jeffrey A. Ogden, Harold M. Kahler, and Stephan Brady, explores contracting issues for Performance-Based Life Cycle Support, and in particular, how to balance long-term commercial partnerships with the need to mitigate financial and operational risks.

The featured book in this issue’s Defense Acquisition Professional Reading List is *Forged in War: The Naval-Industrial Complex and American Submarine Construction, 1940–1961* by Gary E. Weir, reviewed by Stafford A. Ward.



DAU CENTER FOR DEFENSE ACQUISITION RESEARCH

RESEARCH AGENDA 2015

The Defense Acquisition Research Agenda is intended to make researchers aware of the topics that are, or should be, of particular concern to the broader defense acquisition community throughout the government, academic, and industrial sectors. The purpose of conducting research in these areas is to provide solid, empirically based findings to create a broad body of knowledge that can inform the development of policies, procedures, and processes in defense acquisition, and to help shape the thought leadership for the acquisition community.

Each issue of the *Defense ARJ* will include a different selection of research topics from the overall agenda, which is at: <http://www.dau.mil/research/Pages/researchareas.aspx>

Measuring the Effects of Competition

- What means are there (or can be developed) to measure the effect on defense acquisition costs of maintaining an industrial base in various sectors?
- What means exist (or can be developed) of measuring the effect of utilizing defense industrial infrastructure for commercial manufacture in growth industries? In other words, can we measure the effect of using defense manufacturing to expand the buyer base?
- What means exist (or can be developed) to determine the degree of openness that exists in competitive awards?

- What are the different effects of the two best-value source-selection processes (tradeoff vs. lowest price technically acceptable) on program cost, schedule, and performance?

Strategic Competition

- Is there evidence that competition between system portfolios is an effective means of controlling price and costs?
- Does lack of competition automatically mean higher prices? For example, is there evidence that sole source can result in lower overall administrative costs at both the government and industry levels, to the effect of lowering total costs?
- What are the long-term historical trends for competition guidance and practice in defense acquisition policies and practices?
- To what extent are contracts being awarded non-competitively by congressional mandate, for policy interest reasons? What is the effect on contract price and performance?
- What means are there (or can be developed) to determine the degree to which competitive program costs are negatively affected by laws and regulations such as the Berry Amendment and Buy American Act?




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Establishing the Technical **FOUNDATION:** Material Solution Analysis Is More Than Selecting an Alternative

 *Aileen G. Sedmak, Zachary S. Taylor, and
Lt Col William A. Riski, USAF (Ret.)*

Several government and independent studies indicate effective systems engineering and program planning in the early stages of acquisition are essential to controlling costs and improving program results. To lay the foundation for successful and executable programs, This article describes the challenge of conducting good systems engineering and technical planning during the Materiel Solution Analysis (MSA) phase after completion of the Analysis of Alternatives and prior to Milestone A. It also presents the work of the Department of Defense Development Planning Working Group to mitigate this challenge by describing the technical activities in the MSA phase necessary to develop the level of knowledge and system concept maturity necessary to proceed into the next phase of acquisition. These technical activities are represented in a notional MSA Phase Activity Model.

Keywords: *systems engineering (SE), technical planning, Materiel Solution Analysis (MSA) phase, early SE, engineering analysis*



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COMME

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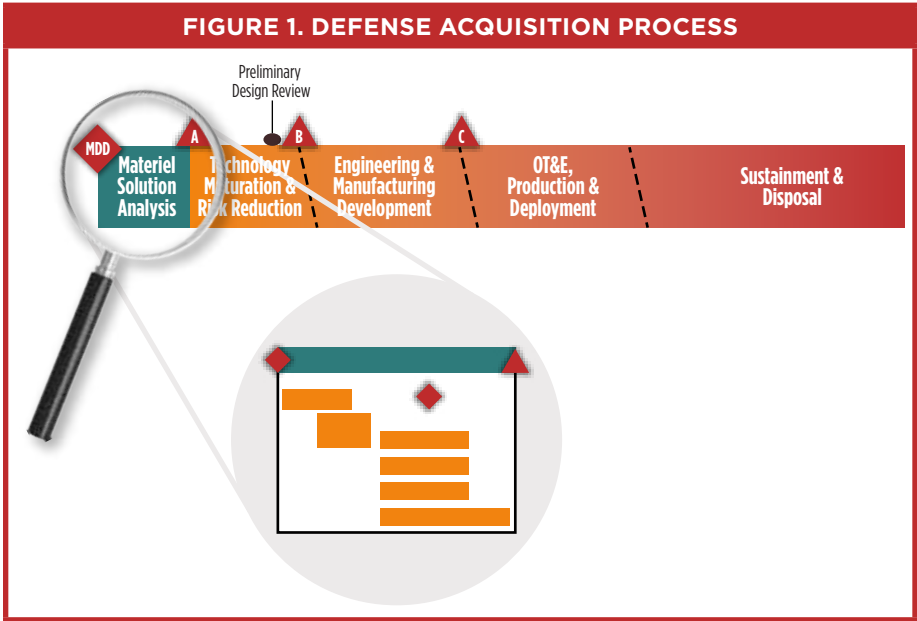
Department of Defense (DoD) weapon systems programs develop some of the most technically advanced and capable systems in the world. Unfortunately, some programs have experienced significant cost and schedule growth, poor technical planning, and inadequate risk management. Several government and independent studies point to early systems engineering and technical planning as key to establishing executable programs and controlling costs later in the acquisition life cycle (U.S. Government Accountability Office [GAO], 2009; National Research Council [NRC], 2008). These studies show that scoping and requirements decisions made prior to Milestone A can have a tremendous impact on downstream development success and production costs. Yet, despite broad recognition that early technical planning is a smart investment, DoD Components reported challenges to obtaining sufficient resources to accomplish these early systems engineering activities. Instead, the focus during the Materiel Solution Analysis (MSA) phase tends to be on the formal Analysis of Alternatives (AoA) and selection of a preferred materiel solution. As such, resources allocated to perform post-AoA systems engineering and technical planning are often inadequate to prepare for the next program milestone and subsequent phase of acquisition.

DoD Components consistently experience difficulty in defending the need for resources to complete systems engineering and technical planning, outside of the AoA, in preparation for Milestone A. This resourcing challenge can partially be attributed to a common misperception that the AoA comprises nearly all of the effort during the MSA phase, and that AoA results are all a program needs to proceed to a Milestone A decision. To address this misperception and to help justify the need for resources for post-AoA systems engineering, the Development Planning Working Group (DPWG), a government-only working group with representation from across the DoD, began an effort to describe the technical activities that should be completed in the MSA phase. This effort focused on developing the level of knowledge and system concept maturity required by policy to proceed into the next phase of acquisition. This article presents the methodology and results of that effort.

Background

As shown in Figure 1, MSA is the first phase in the acquisition process. According to Department of Defense Instruction (DoDI) 5000.02, the purpose of the MSA phase is to conduct the analysis to select a preferred materiel solution, begin translating validated capability gaps into

system-specific requirements, and conduct planning to satisfy the phase-specific criteria for the next program milestone designated by the Milestone Decision Authority (MDA) (DoD, 2015). Commonly, the MDA will decide to invest in technology maturation and preliminary design in the Technology Maturation and Risk Reduction (TMRR) phase.



Note. MDD = Materiel Development Decision; OT&E = Operational Test & Evaluation.

The purpose of the TMRR phase is to reduce technology, engineering, integration, and life-cycle cost risk to the point that a decision to contract for Engineering and Manufacturing Development (EMD) can be made with confidence in successful program execution for development, production, and sustainment (DoD, 2015). Using the TMRR phase for true risk reduction was an initiative of Better Buying Power version 2.0 (Kendall, 2013) and was incorporated into DoDI 5000.02 (DoD, 2015). The TMRR phase also includes the Preliminary Design Review (PDR), which locks down the system's basic architecture and establishes the allocated baseline. Early systems engineering in the MSA phase provides the foundation for TMRR-phase contract award(s) and preliminary design activities. Technical activities in the MSA phase help identify critical technologies, support development of a competitive prototyping strategy, and identify the set of risks that will drive TMRR phase risk-reduction efforts. This early systems engineering work is vital to setting the program up for long-term success.

The DPWG initiated its effort based on three foundational assumptions. These assumptions are supported by studies (GAO, 2009; NRC, 2008) using empirical data of past program performance, as well as observations by acquisition leaders and subject matter experts. These assumptions, along with key supporting evidence, are summarized below.

Assumption 1: DoD programs experience cost, schedule, and performance issues. For years, DoD weapon systems programs have been prone to “significant cost, schedule, and performance problems” (GAO, 2009, p. 25), poor technical planning, and inadequate risk management. In 2008 alone, 96 DoD Major Defense Acquisition Programs (MDAP) experienced a combined cost growth of \$296 billion and an average schedule delay of 22 months (GAO, 2009, p. 1). These overruns have made it difficult for the DoD to equip its warfighters efficiently and effectively to defend against new and emerging threats. In today’s fiscal environment, the challenge has become even more critical.

Assumption 2: Early systems engineering and technical planning can help mitigate these cost, schedule, and performance issues throughout a program’s life cycle. At the request of the Air Force, the NRC conducted a retrospective study in 2008 to assess the contribution of pre-Milestone A and early-phase systems engineering to positive or negative development outcomes. The study’s findings and recommendations are based on case studies of eight Air Force MDAPs and on the subject matter expertise of the committee members. The study found that early systems engineering processes and functions are essential to ensuring programs deliver products on time and on budget, but that current implementation of early systems engineering in the Air Force was unstructured and inconsistent. In particular, the study identified the following tasks that should be completed before Milestone A: consideration of alternative concepts (solutions); setting of clear, comprehensive Key Performance Parameters (KPP) and system requirements; and early attention to interfaces and interface complexity to the Concept of Operations (CONOPS) and to the system verification approach (NRC, 2008). The relevant set of conclusions and recommendations from this study can be found in Appendix A.

Assumption 3: Programs are not adequately resourced to complete sufficient early systems engineering and technical planning. DPWG representatives from each of the DoD Components shared similar experiences regarding difficulty in justifying and obtaining funds for post-AoA systems engineering work to support Milestone A requirements. In some cases, programs attempted to fund this work by including it in the

scope of the AoA, resulting in lengthy and expensive AoAs as noted by the Cost Assessment and Program Evaluation (CAPE) representative. This assumption is also supported by a 2014 follow-up study by the NRC on the effectiveness of Air Force development planning. That study found that the amount of program element funding for Air Force development planning is insufficient and recommended that the Air Force align adequate resources to achieve the desired planning analysis and recommendations (NRC, 2014). The complete set of conclusions and recommendations from the 2014 NRC study can be found in Appendix B.



Approach and Methodology

Despite clear evidence from the NRC study that systems engineering and technical planning in the early phases of acquisition are critical to long-term program success, many programs lacked the necessary resources to adequately complete the post-AoA systems engineering and robustly plan the technical effort for system development. The DPWG decided to address the problem by creating an activity model describing the set of technical activities a defense acquisition program should complete before Milestone A. Using the activity model, program managers could more fully develop the appropriate level of knowledge and system concept maturity necessary to proceed into the next phase of acquisition. The activity model is based on current milestone and phase information requirements in DoDI 5000.02 and can be used to justify and defend the need for resources to complete the

technical activities. The model does not propose any new requirements on programs; it synthesizes existing requirements from several sources and describes the activities necessary to meet those requirements. It was coordinated with representatives from each of the DoD Components.

The DPWG was led by the Office of the Deputy Assistant Secretary of Defense for Systems Engineering and included representatives from each of the DoD Components, the Joint Staff, CAPE, and other offices organizationally aligned under the Office of the Secretary of Defense for Acquisition, Technology, and Logistics. Over the course of 8 months, the DPWG held six workshops to collaboratively examine current requirements regarding Milestone A and the MSA phase, and to explore DoD Component processes for completing the AoA and post-AoA technical planning efforts.

The DPWG used a two-pass approach to identify and organize all potential technical activities into a comprehensive set supported by policy and best practice. The two-pass approach helped ensure that a broad set of technical activities was analyzed and that the set of activities was closely tied to milestone and phase information requirements to support resource justifications. The two-pass approach also ensured that all milestone and phase information requirements were supported by one or more activities in the model.

The first “forward pass” consisted of brainstorming typical technical activities performed in the MSA phase based on the Services’ current policies and processes. As part of this first pass, a standard set of AoA activities was compiled based on an analysis of several recent AoA study plans and AoA reports. This set of AoA activities, confirmed by CAPE, helped to bound the AoA scope and set the stage for identifying the additional technical activities required to prepare for Milestone A and the TMRR phase. The second “backward pass” looked at the technical content of products required at Milestone A and identified activities that are needed to produce that technical information. Any activities identified during the backward pass that were missing were added to the model. Activities that were redundant or not tied to a product or information required at Milestone A were removed from the model.

The intent of the activity model is to help program personnel understand and justify the need for resources to complete adequate systems engineering and technical planning prior to Milestone A. The activity model can also be used to guide programs in planning and executing the MSA phase, ensuring all necessary activities are considered, planned, and resourced. However,

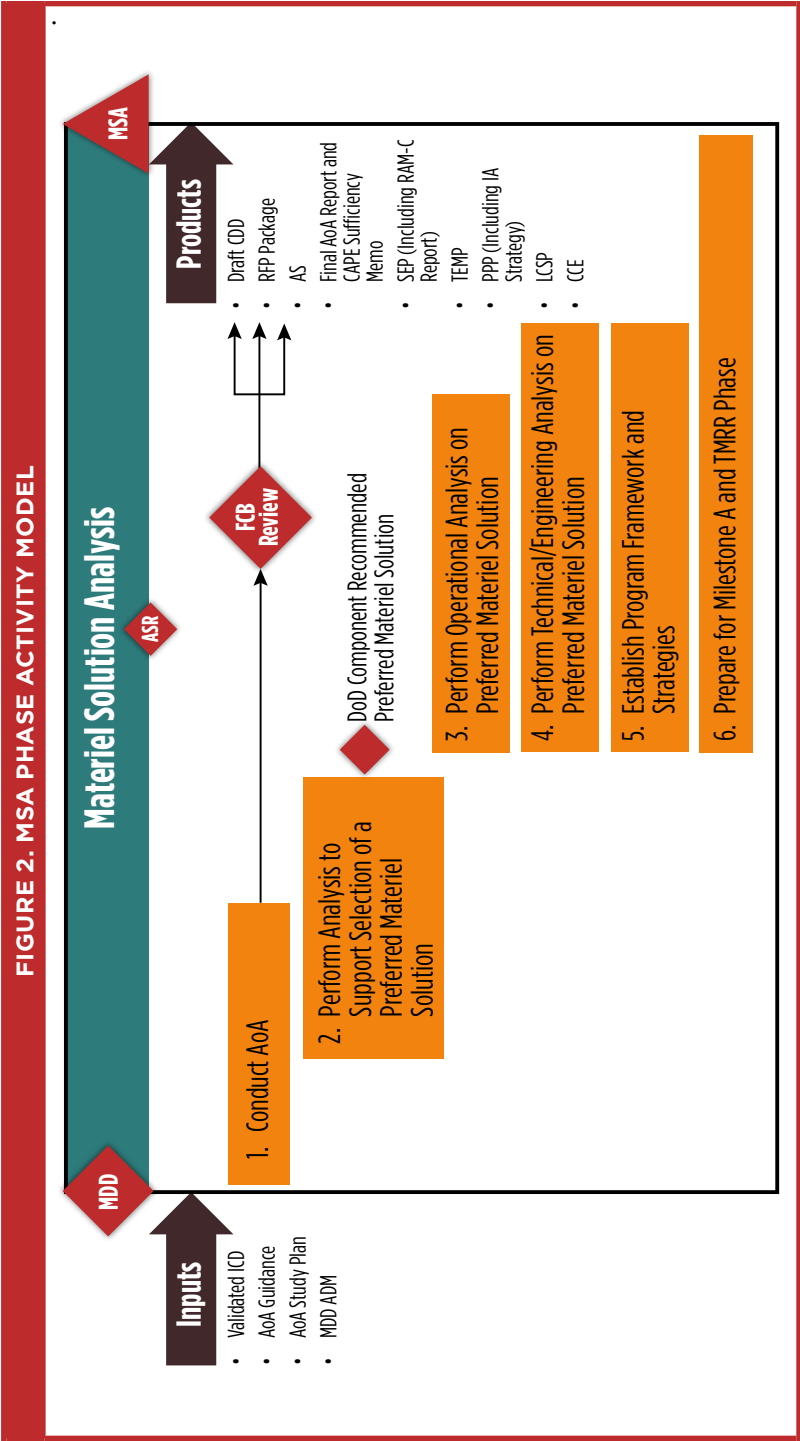
the activity model represents an idealized process, and specific program plans should be characterized by critical thinking, tailored to the product being acquired, and optimized to get the best value for the investment.

The activity model represents an idealized process, and specific program plans should be characterized by critical thinking, tailored to the product being acquired, and optimized to get the best value for the investment.

Findings

The MSA Phase Activity Model developed by the DPWG can be applied across the DoD and includes nominal inputs, technical products, reviews, and technical activities. The model comprises six major activities, each composed of lower-level tasks and subtasks. The six major activities are (a) conduct of the AoA, (b) selection of a preferred materiel solution, (c) operational analysis on the preferred materiel solution, (d) engineering and technical analysis on the preferred materiel solution, (e) development of program plans and strategies, and (f) preparation/run-up for the milestone decision. In many cases, program systems engineers provide essential technical support for several activities or tasks, but do not lead or have decision authority for those activities or tasks. Other functional disciplines also work closely with the systems engineering team during this phase. When completed in concert with other programmatic and acquisition activities, these systems engineering technical activities help develop the appropriate level of knowledge and system concept maturity necessary to proceed into the next phase of acquisition.

Figure 2 depicts the six major activities in the MSA activity model, as well as the key inputs, products, and reviews. The relative start/finish time of each activity is depicted in the figure; however, the durations of activities are nominal and vary based on the program. Many tasks and subtasks are performed concurrently and iteratively within a major activity to help the program refine the attributes and performance parameters, and develop the necessary knowledge and products for Milestone A. The following discussion describes the inputs, products, and reviews in more detail and presents an overview of the activities.



Note. ADM = Acquisition Decision Memorandum; AS = Acquisition Strategy; ASR = Alternative Systems Review; CCE = Component Cost Estimate; FCB = Functional Capabilities Board; IA = Information Assurance; LCSP = Life-Cycle Sustainment Plan; PPP = Program Protection Plan; RAM-C = Reliability, Availability, Maintainability, and Cost; SEP = Systems Engineering Plan; TEMP = Test and Evaluation Master Plan.

MSA Phase Inputs

The MSA phase begins after a favorable Materiel Development Decision (MDD), when the MDA authorizes entry into the Defense Acquisition System. Based on MDD review criteria found in DoDI 5000.02, *Operation of the Defense Acquisition System*, the following are included as inputs for the MSA Phase Activity Model (DoD, 2015):

- Initial Capabilities Document (ICD) validated by the Joint Requirements Oversight Council
- AoA Study Guidance written and approved by the director, CAPE
- AoA Study Plan written by the DoD Component and approved by the director, CAPE

An Acquisition Decision Memorandum (ADM), signed by the MDA, authorizes entrance into the MSA phase and is also considered an input to the MSA Phase Activity Model.

According to Chairman of the Joint Chiefs of Staff Instruction (CJCSI) 3170.01I, *Joint Capabilities Integration Development System*, the ICD formally documents the results of the Capabilities-Based Assessment (CBA) (Chairman of the Joint Chiefs of Staff [CJCS], 2015a). The CBA and other relevant studies, including their associated information and data such as that generated by models and simulations, may be useful for understanding the operational need and context. These studies should be made available to the AoA study team and the program manager during the MSA phase.

An important component of the MDA's decision to proceed into the MSA phase is based on effective development planning leading up to MDD. Before MDD, the DoD Component is expected to conduct early systems engineering analyses to provide an assessment of whether the proposed candidate materiel solution approaches are technically feasible and have the potential to effectively address capability gaps, desired operational attributes, and associated external dependencies. The DoD Component is also expected to develop the plan to staff and fund the activities preceding the next decision point, such as analytic, engineering, and programmatic activities, and show that this plan is complete and fully resourced (DoD, 2015).

MSA Phase Technical Products

For the MSA Phase Activity Model, Milestone A is assumed to be followed by the TMRR phase. DoDI 5000.02 contains a complete list of statutory and regulatory requirements for Milestone A. Some regulatory

requirements may be tailored by the MDD ADM. The Milestone A decision approves program entry into the TMRR phase as well as release of the final Requests for Proposal (RFP) for TMRR contracts (DoD, 2015).

CJCSI 3170.01I (CJCS, 2015a) contains a requirement for a draft Capability Development Document (CDD) to be written during the MSA phase to inform the Acquisition Strategy (AS) and system performance specification, and to guide TMRR phase efforts. The draft CDD specifies capability requirements in terms of developmental KPPs, Key System Attributes (KSA), and Additional Performance Parameters (APA), and is based on the capability requirements and capability gaps specified in the ICD. The Joint Staff policy (CJCS, 2015b) states:

The post-AoA review shall be completed in sufficient time to permit Sponsor preparation of a draft CDD or similar documentation prior to Milestone A, not submitted to the Gatekeeper for staffing and validation at that time, to inform the development of the request for proposals in support of the TMRR Phase. (p. A-15)



Based on the policies described previously, the following set of Milestone A products incorporates technical content and is supported by MSA activities included in the MSA Phase Activity Model:

- Draft CDD
- RFP package for TMRR phase contracts
- AS
- Final AoA Report, including AoA sufficiency memo signed by the director, CAPE
- Systems Engineering Plan (SEP), including the initial Reliability, Availability, Maintainability-Cost (RAM-C) Rationale Report as an attachment
- Test and Evaluation Master Plan (TEMP)
- Program Protection Plan (PPP), including the Cybersecurity Strategy
- Life-Cycle Sustainment Plan (LCSP)
- Component Cost Estimate (CCE)

Reviews Conducted During the MSA Phase

During the MSA phase, the program may conduct an Alternative Systems Review (ASR) to support a dialogue between the end user and the acquisition community, which leads to a draft system performance specification for the preferred materiel solution (Defense Acquisition University [DAU], 2013). The draft system performance specification defines the performance requirements in terms of the required results and the criteria for verifying compliance, the operational environment, and the interface and interoperability requirements (Defense Standardization Program, 2009). Through the ASR, the program should evaluate whether the proposed set of requirements satisfies the customers' needs and expectations, and whether there is sufficient understanding of the technical maturity, feasibility, and risk of the preferred materiel solution to proceed into the next phase (DAU, 2013).

CJCSI 3170.01I (CJCS, 2015a) requires a post-AoA review of AoA results and other engineering analysis before Milestone A. The post-AoA review should establish mutual understanding of the operational capability needs in the ICD; the proposed KPPs in the draft CDD; and the maturity, feasibility, and risks of the preferred materiel solution. As stated in policy (CJCS, 2015b):

Following Sponsor completion of the AoA, the post-AoA review provides the validation authority and other stakeholders the opportunity to assess how the different alternatives address the validated capability requirements and associated capability gaps, and at what life cycle costs. (p. A-15)

... The post-AoA review is not a validation of the AoA results, but rather informs the validation authority's advice to the Milestone Decision Authority (MDA) on the AoA results, recommended alternative(s), and proposed KPPs, KSAs, and APAs. The validation authority may recommend alternative(s) different from those recommended by the Sponsor when such a recommendation would better serve the management and prioritization of the capability requirement portfolio. (p. A-16)

Completion of the ASR and post-AoA review helps to ensure the expected performance attributes and system capabilities are consistent with customer needs, and guide the additional engineering and technical analysis needed to prepare the draft CDD and the system performance specification.


MSA Phase Activities

The systems engineering effort in the MSA Phase Activity Model is broken into three levels of increasing detail. Activities are defined as major efforts aimed at achieving a common outcome or contributing to a set of related products. Six activities constitute the MSA Phase Activity Model, including conduct of the AoA. Tasks and subtasks are more detailed and are performed in support of an activity. Tasks and subtasks often focus on a single product or outcome, such as the system performance specification or PPP. A description of the tasks and subtasks associated with each major activity follows.


Activity 1: Conduct AoA. The AoA encompasses all efforts and analyses conducted by the AoA study team under the direction of the Senior Advisory Group/Executive Steering Committee (SAG/ESC) and CAPE (DoD, 2015). The objective of the AoA is to characterize and analyze each candidate materiel solution relative to the others. Candidate materiel solutions are characterized by identifying key attributes and performance measures (discriminators), unique logistics or information support needs, operational dependencies, and concepts of employment. This characterization of alternatives may be completed using market research, relevant trade studies, or information obtained from industry (e.g., through Requests for Information

or funded concept definition studies). The AoA study team then examines the operational effectiveness and operational suitability of each candidate materiel solution against appropriate measures of effectiveness and measures of performance, based on selected missions, threats, and scenarios. The AoA also includes an initial risk analysis for each candidate materiel solution. The risk analyses examine technical risks encompassing technology, engineering, integration, and manufacturing, as well as cost, schedule, and operational risks. Finally, initial life-cycle cost estimates are provided for each candidate materiel solution.

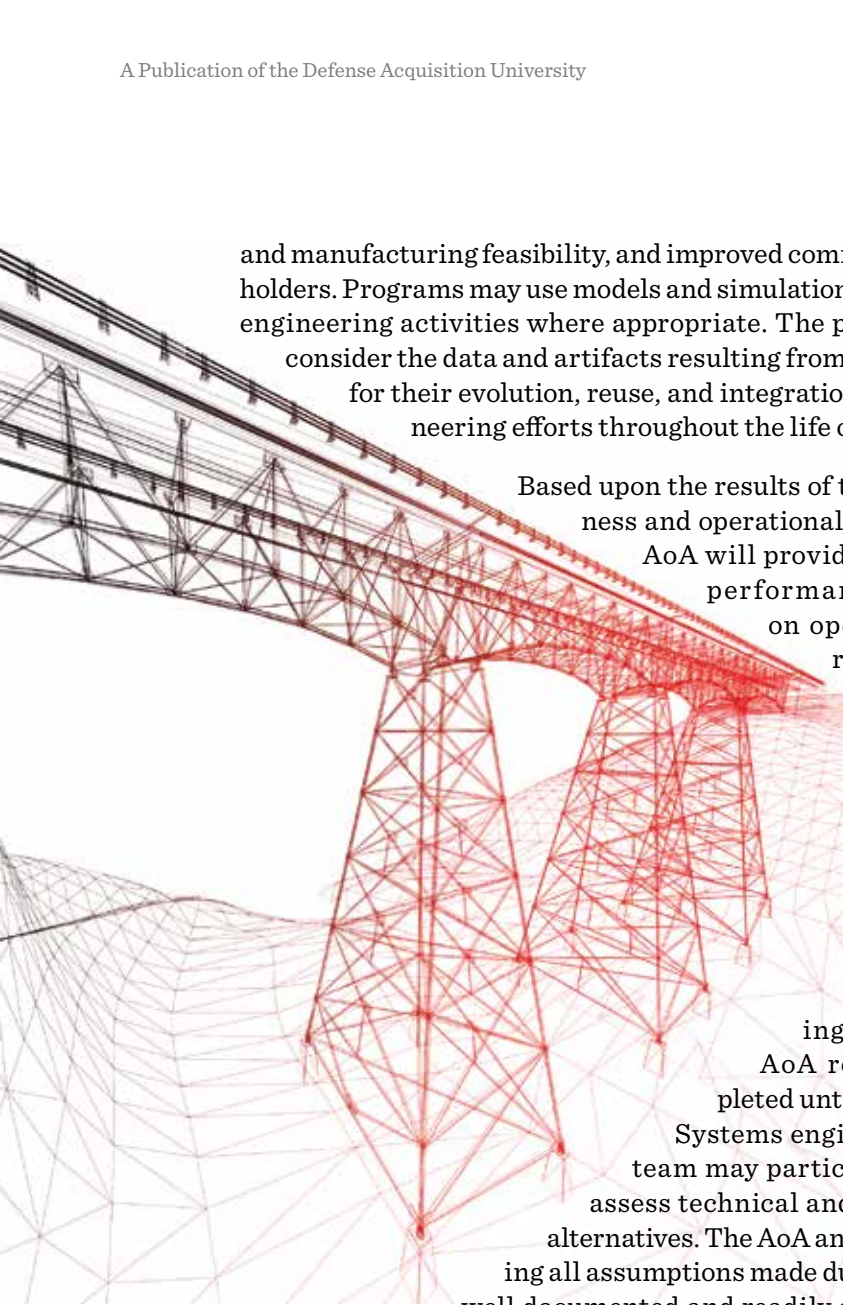
It is important to note for several reasons that completion of the AoA does not mean the system concept is ready to proceed to Milestone A. First, the AoA supports a decision on the preferred materiel solution, but does not directly recommend a preferred solution. Analysis should be performed to assess affordability and other constraints to determine which solution the DoD Component should pursue. Second, the AoA may not take into account certain factors if they are deemed not to be discriminators. For example, a system attribute such as reliability may not be a discriminator during the AoA because all of the alternatives under consideration have comparable reliability characteristics. Reliability would not be included in the analysis because it does not help differentiate between alternatives, but further engineering analysis on system reliability would need to be completed on the preferred materiel solution to satisfy Milestone A review criteria and develop appropriate performance specifications. Finally, significant effort is needed to develop detailed program planning and cost estimates to support the next program milestone and subsequent phases.



It is important to note for several reasons that completion of the AoA does not mean the system concept is ready to proceed to Milestone A.



Several tools and methodologies may be used to support the AoA and other MSA phase tasks. For example, models and subsequent simulations are tools that can help facilitate a better understanding of the mission context, a more complete evaluation of the trade space, earlier assessment of technical



and manufacturing feasibility, and improved communication among stakeholders. Programs may use models and simulations to support analysis and engineering activities where appropriate. The program manager should consider the data and artifacts resulting from these activities and plan for their evolution, reuse, and integration into program and engineering efforts throughout the life of the program.

Based upon the results of the operational effectiveness and operational suitability analyses, the AoA will provide thresholds for certain performance parameters based on operational requirements related to the mission.

These thresholds will inform the development of KPPs, KSAs, and APAs in the draft CDD (CJCS, 2015b).

In the MSA Phase Activity Model, the AoA concludes with the final SAG/ESC meeting, even though the final

AoA report may not be completed until later in the MSA phase.

Systems engineers from the program team may participate in the AoA to help assess technical and engineering risk of the alternatives. The AoA analysis and results, including all assumptions made during the study, should be well documented and readily available to the program team so they can fully understand the results and be able to build on these initial efforts.

Activity 2: Perform analysis to support selection of a preferred materiel solution. Using the AoA results, the DoD Component should conduct additional analyses to support the selection of a preferred materiel solution from the remaining candidate materiel solutions trade space. The additional analyses may address affordability, operational effectiveness

and suitability, and/or technical/engineering challenges and trends aimed at balancing cost, performance, schedule, and risk to determine the DoD Component-selected preferred materiel solution.

Affordability analysis is a DoD Component leadership responsibility that involves looking across the portfolio to make responsible investment decisions based on current and future capability needs (DoD, 2015). The program may support the DoD Component affordability analysis by examining the impact of a new materiel solution on current and planned systems, as well as the impact of those systems on a new program. A broader look at portfolio capabilities, system of systems (SoS) dependencies, and funding obligations may reveal technical, cost, and schedule risks that drive the selection of the preferred materiel solution. The affordability analysis also will inform the affordability cost goal set at Milestone A (DoD, 2015).

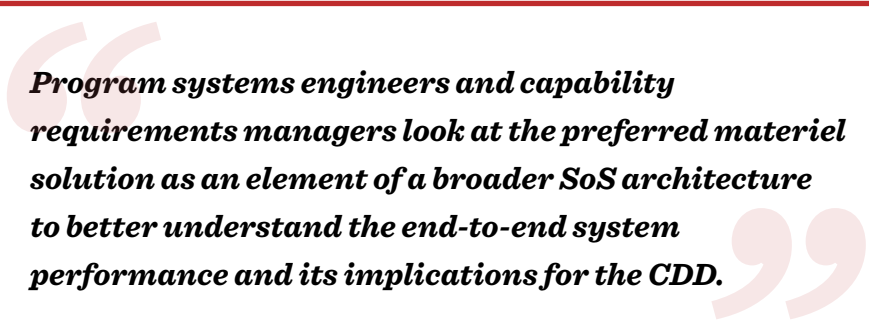
This activity ends after the DoD Component has selected which materiel solution it will pursue. All work after this point is concentrated on maturing the preferred materiel solution and preparing for the Milestone A decision.

Activity 3: Perform operational analysis on preferred materiel solution. This activity begins after the DoD Component has selected a preferred materiel solution, and it is often completed concurrently and iteratively with technical/engineering analysis, development of program frameworks and strategies, and preparation for Milestone A. After the DoD Component has selected a preferred materiel solution, the program team refines the operational context for the system concept and may provide technical justification to refine the operational requirements. These refinements should build upon AoA results and the subsequent analysis, and will support the post-AoA review to ensure user buy-in on the proposed solution and operational concepts (CJCS, 2015a). The program should maintain a working relationship with end users to achieve a balance between user requirements (documented in the draft CDD), cost, and technical feasibility.

During the AoA, accurate and complete CONOPS and mission threads provide a strong operational foundation for evaluating alternatives and assessing operational effectiveness and suitability. After the AoA is complete, the DoD Component combat developer creates an Operational Mode Summary/Mission Profile (OMS/MP) that includes the operational tasks, events, durations, frequency, operating conditions, and environment for the preferred materiel solution. The program team uses the OMS/MP to better understand the context in which the potential system concept will be employed and how this context affects the system acquisition, including

programmatic, and technical interfaces and interdependencies (DoD, 2015). The program team also uses the OMS/MP to develop system performance and sustainment requirements, and analyze SoS impacts.

Program systems engineers and capability requirements managers look at the preferred materiel solution as an element of a broader SoS architecture to better understand the end-to-end system performance and its implications for the CDD, including external interfaces and interoperability constraints. This SoS-focused analysis may identify changes in other systems needed to fully address the capability gap. The DoD Architecture Framework provides one approach for capturing and presenting architectural data, including operational context and system dependencies. This standardized approach can facilitate improved communication and sharing of technical information among various stakeholders.



Program systems engineers and capability requirements managers look at the preferred materiel solution as an element of a broader SoS architecture to better understand the end-to-end system performance and its implications for the CDD.

Operational analysis also includes identification of changes to Doctrine, Organization, Training, materiel, Leadership and Education, Personnel, Facilities, and Policy (DOTmLPF-P) that must be planned, tracked, and implemented for the materiel solution to be effective when it becomes available. DOTmLPF-P Change Recommendations (DCR) may be identified by the systems engineering team, but it is the DoD Component's responsibility to implement the DCR.

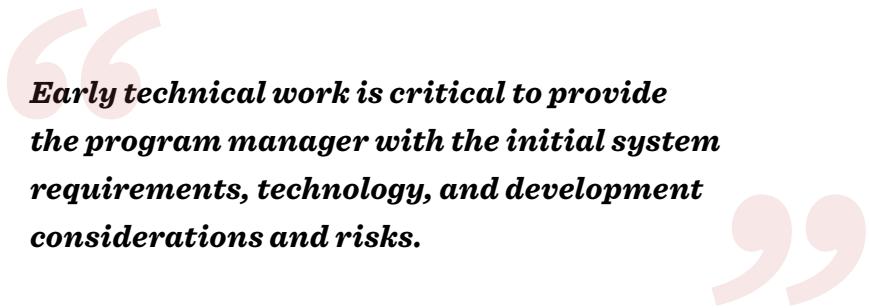
The program team also assesses the system-level performance parameter thresholds generated during the AoA to develop the candidate KPPs, KSAs, and APAs that will be documented in the draft CDD. Operational sustainment requirements such as materiel availability, operational availability, and reliability are also refined or developed. These key requirements are briefed to the validation authority along with the results of the AoA and other analyses to ensure the proposed solution will meet the needs of the warfighter (CJCS, 2015a, 2015b).

Activity 4: Perform technical/engineering analysis on preferred materiel solution. After the DoD Component selects a preferred materiel solution, the program team begins its technical and engineering analysis, which builds upon the results of the AoA and pre-MDD technical effort. Technical analysis and engineering tasks and subtasks are often conducted iteratively to refine the parameters and attributes of the preferred materiel solution. Primary engineering tasks include conducting trade studies and sensitivity analyses, assessing technical feasibility and risk, and performing functional analysis around mission tasks in the OMS/MP. Engineering and technical analysis results in the preliminary system functional baseline, including system performance requirements, interface requirements, certain environmental or design constraints, notional system architecture design, and initial manufacturing planning. Early technical work is critical to provide the program manager with the initial system requirements, technology, and development considerations and risks. This early analysis also provides essential information on test and evaluation issues, support and maintenance objectives, work scope, and cost and schedule drivers. All of these factors affect the acquisition approach developed by the program manager and addressed in the AS.

The engineering analysis includes identifying potential hardware and software options required for implementation. The program team, as part of its system solutions analysis, conducts a technology maturity assessment of the hardware and software options with a focus on identifying critical technologies. Critical technologies become one basis for risk reduction and prototype efforts identified in program plans and executed during the TMRR phase. These prototype efforts should also be used to evaluate manufacturing processes.

The program team should conduct reliability and maintainability (R&M) engineering to develop maintenance and support concepts, articulate R&M and sustainment requirements, and establish goals for R&M performance throughout the acquisition process. R&M performance includes not only the estimated R&M requirements relating to design, but also other critical life-cycle support parameters. R&M engineering subtasks help program personnel to identify and reduce R&M risks, and mitigate operational and maintenance impacts of these risks. The RAM-C Rationale Report, attached to the SEP at Milestone A, documents the rationale for sustainment KPPs (Office of the Secretary of Defense, 2009).

It is important for the program to conduct initial program protection analysis and planning during the MSA phase to design the system concept with system security in mind and to manage risks associated with critical program information and mission-critical functions. The PPP outline identifies tasks a program should conduct at this point in the acquisition process. Systems engineers should (a) conduct an initial criticality analysis to identify mission-critical functions; (b) identify candidate-critical program information; (c) identify potential threats, vulnerabilities, and countermeasures; (d) develop the Cybersecurity Strategy; and (e) document the findings within the PPP (Kendall, 2011b).



Early technical work is critical to provide the program manager with the initial system requirements, technology, and development considerations and risks.

Activity 5: Establish program framework and strategies. Concurrent with operational and engineering analysis, the program team determines the overall acquisition strategy and program framework driving the technical effort in later phases. This strategy may include plans for technology development, competitive prototyping, test and evaluation, and management of systems engineering processes, among others.

Comprehensive program and technical planning includes several basic program planning elements, which all programs should address and document in the appropriate Milestone A documents: AS, SEP, TEMP, PPP, and LCSP. These planning elements are based on the expected content for each planning document, according to approved outlines (Kendall, 2011a, 2011b, 2011c).

The MSA Phase Activity Model contains 11 tasks required to establish the program's acquisition strategy and management framework, which map directly to the planning elements discussed in this section. These tasks span multiple disciplines and include, among others, defining the program management approach (i.e., managing schedule and resources); developing

the systems engineering approach for technology maturation, design, and development; defining plans to manage key interfaces (both technical and programmatic); and defining plans and processes to manage risks.

Activity 6: Prepare for Milestone A and TMRR phase. Finally, the program pulls together the technical and programmatic analysis and coherent set of plans and technical data developed throughout the MSA phase to satisfy the review criteria for Milestone A. This activity includes supporting the development of program documents required at Milestone A (e.g., SEP, AS, PPP, etc.), providing technical content for the RFP package for the TMRR phase, and supporting other contracting activities with technical considerations. In preparation for the Milestone A Defense Acquisition Board, the program should anticipate several key questions, including what has the program learned during the MSA phase, how will the program apply this knowledge going forward, and why is the program ready to proceed into the recommended next phase?

The primary RFP technical content is contained in the system performance specification, Statement of Work, technical evaluation criteria, and the Contract Data Requirements List. The program office and DoD Component may conduct a government-only requirements review to agree on the performance specification requirements to be included in the RFP and their traceability back to the draft CDD.

Other operational analysis is conducted during the MSA phase with a focus on the preferred materiel solution, and its operational context and constraints. This activity, along with any necessary update to the results and recommendations of the AoA study, is captured in a draft CDD. The draft CDD should contain at least the following sections (CJCS, 2015b):

- Operational Context, with focus on the operational context and the CONOPS.
- Capability Discussion, with focus on previously validated capability requirements being addressed in the draft CDD.
- Program Summary, with focus on the synchronization of SoS efforts across other CDDs, Capability Production Documents, and Joint DCR.
- Development KPPs, KSAs, and APAs, with a focus on the initial/draft performance attributes resulting from the AoA or other studies/analyses.

- Other System Attributes, with a focus on attributes that require significant TMRR phase efforts.
- Technology readiness assessment, with a focus on identifying critical technologies that need to be matured during the TMRR phase.

This activity ends with a successful Milestone A decision, which authorizes the program to enter the TMRR phase and grants funding to complete TMRR activities.

Conclusions

The DoD recently revised and reissued the information required to support the MDA's deliberations at Milestone A to approve a program's transition to the next phase (DoD, 2015). These milestones and phase information requirements provide confidence to the decision authority that thoughtful and comprehensive plans are in place. For this to occur, resources must be provided to perform the activities to analyze and determine strategies and plans from multiple perspectives (i.e., requirements, costs, trade-offs, risks, etc.) The DPWG developed a coherent and complete set of technical activities that provides context beyond systems engineering, but also details the systems engineering activities that bridge the gap between the AoA and the milestone and phase information requirements for the selected solution to be presented at Milestone A. This activity model can be used to estimate and justify the resources needed to successfully transition from the selection of a preferred solution through a favorable Milestone A decision.

As informed as this MSA activity model is, more research could be performed to move toward evidence-based policy in the DoD. For example, the plans, specifications, and other information requirements needed for Milestone A are a necessary, but not sufficient, element of a program's success. Given the complexity of today's MDAPs, acquisition timelines are measured in years, not months. It may be reasonable to focus some research on evaluating the correlation between perceived program success coming out of a system-level PDR and the program's plans previously established at Milestone A.

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Appendix A

2008 NRC Study Findings and Recommendations

At the request of the Air Force, the National Research Council conducted a retrospective study in 2008 examining the role that systems engineering can play during the defense acquisition life cycle in addressing the root causes of program failure, especially during the pre-Milestone A and early phases of a program. Paul G. Kaminski and Lester L. Lyles led a committee that produced findings (i.e., conclusions) and recommendations based on case studies of eight Air Force MDAPs and on the subject matter expertise of the committee members. The study found early systems engineering processes and functions were essential to ensuring programs deliver products on time and on budget, but that current implementation of early systems engineering in the Air Force was unstructured and inconsistent. Their report made seven recommendations, of which two are relevant to systems engineering processes and activities. These two are highlighted in the complete list of recommendations below.

RECOMMENDATIONS
Ch 3 SYSTEMS ENGINEERING WORKFORCE
The Air Force should assess its needs for officers and civilians in the systems engineering field and evaluate whether either its internal training programs, ..., or external organizations are able to produce the required quality and quantity of systems engineers and systems engineering skills.
The Air Force should support an internal systems engineering career track that rewards the mentoring of junior systems engineering personnel, provides engineers with broad systems engineering experience, provides appropriate financial compensation to senior systems engineers, and enables an engineering career path into program management and operations.
Decisions made prior to Milestone A should be supported by a rigorous systems analysis and systems engineering process involving teams of users, acquirers, and industry representatives.
Ch 4 SYSTEMS ENGINEERING FUNCTIONS AND GUIDELINES
The Air Force leadership should require that Milestones A and B be treated as critical milestones in every acquisition program and that a checklist such as the “Pre-Milestone A/B Checklist” suggested by the committee be used to judge successful completion.
The committee believes that the Air Force should strive to structure major development programs so that initial deployment is achieved within, say, 3 to 7 years.

RECOMMENDATIONS, CONTINUED

Ch 4 SYSTEMS ENGINEERING FUNCTIONS AND GUIDELINES

The committee recommends that the Air Force place great emphasis on putting seasoned, domain-knowledgeable personnel in key positions—particularly the program manager, the chief system engineer, and the person in charge of “requirements”—and then empower them to tailor standardized processes and procedures as they feel is necessary.

A development planning function should be established in the military departments to coordinate the concept development and refinement phase (now Materiel Solution Analysis and Technology Maturation and Risk Reduction phases) of all acquisition programs to ensure that the capabilities required by the country as a whole are considered and that unifying strategies such as network-centric operations and interoperability are addressed.

Of their 24 findings, 15 are associated with the two highlighted recommendations above and are directly relevant to systems engineering processes and activities.

Chapter	Findings
Chapter 2 Relationship Between Systems Engineering and Program Outcome	There is a need to establish and nurture a collaborative user/acquirer/industry team pre-Milestone A to perform system trade-offs and manage overall system complexity.
	One must clearly establish a complete and stable set of system-level requirements and products at Milestone A.
	It is necessary to manage the maturity of technologies prior to Milestone B and to avoid reliance on immature technologies.
Chapter 3 Systems Engineering Workforce	The government, Federally Funded Research and Development Centers, and industry all have important roles to play throughout the acquisition life cycle of modern weapon systems.
	The source selection for system development and demonstration (now Engineering, Manufacturing and Development [EMD]) should not be made until after the work associated with Milestones A and B is complete.
	Working together, government and industry can develop and explore solutions using systems engineering methodology to arrive at an optimal systems solution.

Chapter	Findings
Chapter 4 Systems Engineering Functions and Guidelines	There must be tight collaboration between user and developer in all pre-Milestone A activities, especially in all systems engineering activities.
	Attention to a few critical systems engineering processes and functions, particularly during preparation for Milestones A and B, is essential to ensuring that Air Force acquisition programs deliver products on time and on budget.
	The development time issue is addressable by applying systems engineering to key risk drivers, technology maturity, and external interfaces before Milestones A and B.
	The definition of clear Key Performance Parameters (KPP) by Milestone A and clear requirements by Milestone B that can remain stable through Initial Operational Capability (IOC) can be essential to an efficient development phase.
	It is also important that critical technologies be sufficiently mature prior to starting System Development and Demonstration (now EMD).
	The committee observed that although today's systems are not necessarily more complex internally than those of 30 years ago, their external complexity often is greater, because today's systems are more likely to try to meet many diverse and sometimes contradictory requirements from multiple users. This kind of complexity can often lead to requirements being changed between Milestone B and IOC, and it can lead to relying on immature technology.
	The committee believes that the accumulation of processes and controls over the years—well meant, of course—has stifled domain-based judgment that is necessary for timely success. Formal systems engineering processes should be tailored to the application. But, they cannot replace domain expertise.
	Identification of alternatives, of risk drivers, and of external interfaces should be completed before the Analysis of Alternatives (AoA).
	Many aspects of KPPs, Concept of Operations, cost and schedule, performance assessments, risk, and implementation strategy may be addressed after the AoA.

Appendix B

2014 National Research Council Study Findings and Recommendations

In 2013, the Air Force Studies Board of the National Research Council sponsored the committee on Improving the Effectiveness and Efficiency of U.S. Air Force Pre-Acquisition Development Planning, led by Claude Bolton and Paul Kaminski. The committee was asked to provide recommendations on the following topics:

1. How can development planning be improved to help improve near-term acquisition decisions?
2. How can development planning be improved to help concepts not quite ready for acquisition become more mature, perhaps by identifying the need for more engineering analysis, hardware prototyping, etc.?
3. How can development planning be improved to enable the development of corporate strategic plans, such as science and technology investment roadmaps, Major Command capability roadmaps, workforce development plans, etc.?
4. How can development planning be used to develop and train acquisition personnel?

The committee's report, issued in 2014, provided the following recommendations. Those recommendations that are relevant to pre-Milestone A systems engineering processes and activities, or to adequate funding of these activities, are highlighted.

Recommendation 1. The Air Force should redefine development planning as “a key process to support the Secretary of the Air Force and the Chief of Staff of the Air Force in strategic decisions that guide the Air Force toward mission success today and in the future, within available funds and with acceptable risk.”

Recommendation 2. The Chief of Staff of the Air Force and the Secretary of the Air Force should claim ownership of development planning in the Air Force and provide top-level guidance and leadership to all Air Force organizations

responsible for carrying out development planning. This leadership should encourage and facilitate interaction among these organizations.

Recommendation 3. The Air Force should enhance its strategic planning and programming process with a Chief of Staff of the Air Force planning team function that reports to the Chief of Staff of the Air Force with the primary responsibility for integrating development planning across Air Force core functions and coordinating it with Core Function Leads.

Recommendation 4. The Air Force should develop and standardize the use of capability collaboration teams across all Service core functions as a means to facilitate development planning.

Recommendation 5. The Air Force should align adequate resources to ensure the success of the Chief of Staff of the Air Force planning team and its interactions with the capability/collaboration teams to enhance Air Force development planning. The key element of the development planning process provided by the Deputy Chief of Staff for Operations, Plans and Requirements, is the targeted Core Function Support Plan, which starts with the 12 Core Function Leads identifying and prioritizing capability gaps. The resources needed should provide focused support from the Core Function Leads; the necessary analytical and technical capabilities of the personnel comprising and supporting the Chief of Staff of the Air Force planning teams and the capability collaboration teams; and the financial means to achieve the desired planning analysis and recommendations.

Recommendation 6. The Secretary of the Air Force and the Chief of Staff of the Air Force should emphasize development planning as a key workforce development tool for Air Force science and technology, acquisition, and operational personnel. In emphasizing this development, lessons learned from initiatives such as the U.S. Special Operations Command GHOST (Geurts Hands-On Support Team) initiative and its related “Revolutionary Acquisition

Techniques Procedure and Collaboration” forum should be captured and examined for application to the broader development planning tool set. In this sustained emphasis on development planning, analytical skills, technical innovation, concept development, systems engineering rigor, and excellence become part of the broader Air Force culture.

Recommendation 7. The Air Force should periodically assess how well development planning is meeting its overall objective of providing the necessary support for the strategic decisions that guide the Air Force toward mission success, within available funds and with acceptable risk. A systematic approach would include identifying weaknesses, shortcomings, and failures; the causes of these; and ways to address them in the next stages.

Their recommendations are drawn from a set of conclusions based on the subject matter expertise of committee members and interviews with Service leaders, representatives from three Air Force major commands, and two Air Force product centers where development planning takes place. The conclusions are summarized below.

CONCLUSIONS

Lack of focused responsibility, capability, and funding for cross-core function analysis and trade-offs has limited the effectiveness of Air Force Development Planning (AF DP).

The amount of program element funding for development planning is insufficient to perform effective DP.

AF DP is not effective at leveraging promising low-Technology Readiness Level laboratory-developed technology.

Air Force Science and Technology (AF S&T) planning process is insufficiently mature to demonstrate how S&T investments should best be linked to prioritized Air Force needs.

AF DP is not effective at leveraging industry Independent Research and Development investments.

AF DP recognizes the increasing importance of the cyber domain, but lacks the priority, policies, flexibility, and procedures in the development planning and end-to-end acquisition processes to address the cyber security topic effectively.

AF DP does not always help improve near-term acquisition decisions.

CONCLUSIONS, CONTINUED

AF DP does not always help mature pre-acquisition concepts by identifying specific needs for more engineering analyses, prototyping, and technology development, among other factors.

AF DP is not adequately influencing S&T, acquisition, and operational workforce development.

The key element of the development planning process provided by the Deputy Chief of Staff for Operations, Plans and Requirements, is the targeted Core Function Support Plan, which starts with the 13 core function lead integrators identifying and prioritizing capability gaps.

Biographies



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REQUIREMENTS Engineering in an **AGILE** Software Development **ENVIRONMENT**

 *W. Allen Huckabee*

The Business Capability Lifecycle (BCL) methodology, which was implemented to develop defense business systems, requires a change in requirements engineering processes. Previous software development work by Systems, Applications, and Products on the Global Combat Support System-Army (GCSS-Army) followed the waterfall Software Development Life Cycle (SDLC), which is not acceptable in the BCL methodology. The typical functional requirement statement is not easily changed and introduces problems into an Agile SDLC. In this article, the author posits that Agile-based require-





ments (user story and acceptance criteria) best fit the BCL approach. By implementing best business practices and lessons learned from the GCSS-Army project, a typical BCL-led program can achieve significant benefits, such as (a) increased effectiveness in requirements meeting the users' needs; (b) increased performance of customers and software developers; and (c) reduced requirements volatility.

Keywords: *Agile, Business Capability Lifecycle (BCL), Investment Management (IM), requirements engineering, Software Development Life Cycle (SDLC)*


The Business Capability Lifecycle (BCL) is an “overarching framework” implemented by the Department of Defense (DoD) to “rapidly deliver” (Defense Acquisition University [DAU], 2013, p. 3) useful information technology (IT) capabilities to DoD users. The framework mandates the use of iterative development processes to deliver IT capabilities in “18 months from its Milestone B to Full Deployment Decision (FDD)” (p. 4). As the DoD moves toward becoming more integrated using Enterprise Resource Planning (ERP) systems, this article makes the case that the standard requirement statement and Work Breakdown Structure (WBS)-driven waterfall Software Development Life Cycle (SDLC) are not advantageous to the compressed cycle time required by the BCL methodology. In fact, lessons learned from the Global Combat Support System-Army (GCSS-Army), which replaced the existing suite of legacy Standard Army Management Information Systems, suggest that the standard Statement of Requirements-driven development is not as efficient as other methodologies. This article proposes that many benefits can be gained by performing more elaborate requirements engineering processes during the Investment Management (IM) phase of the BCL, using Agile-based user stories and acceptance criteria for integrating the Army’s remaining logistics and tactical finance capabilities into GCSS-Army, while following the BCL methodology (DAU, 2013).

This article reports on a case study of project requirement-engineering processes and documentation of an ERP software development project, which seeks to identify the potential benefits of using Agile-based requirements-engineering processes. The project under analysis transitioned from the waterfall SDLC to an Agile SDLC. A limitation of this study is that access to quantitative data was restricted; therefore, such data could not be used in this study. A second limitation is that this article only addresses functional requirement statements, and therefore, quality and technical requirements are not addressed.



This article is organized in the following manner. First, a review of literature discusses common requirements-engineering processes used in typical software development projects. The final sections provide an overview of the requirements engineering process used on the GCSS-Army project, along with some lessons learned and benefits observed, followed by conclusions.

Literature Review



A review of business requirements-engineering literature highlights three general requirements-engineering processes used in the software development process: functional requirement statements (Institute for Electrical and Electronics Engineers [IEEE], 1998, p. 37), use cases (Regnell, Kimbler, & Wesslén, 1995), and Agile-user stories (Layman, Williams, Damian, & Bures, 2006). Paetsch, Eberlein, and Maurer (2003) defined requirements engineering as a process by which valid requirements are “identified, analyzed, and documented for the system being developed” (p. 1). These researchers suggested the main goal of traditional requirements-engineering activities is to “know what to build before system development starts” (p. 1). Generally speaking, this helps in reducing the cost of rework later in system development. Traditional methods typically utilize functional requirement statements, Software Requirements Specification (SRS) documentation, and use cases as methods of describing “what is to be done, but not how they are implemented” (Paetsch et al., p. 1). Additionally, these requirements engineering activities work very well with waterfall methods, but are not effective in iterative SDLCs. However, Paetsch et al. suggested that Agile requirements-engineering methods can be productive in an iterative development environment where software can be delivered faster, with “improved customer satisfaction and frequently delivered working software” (p. 1) utilizing user stories with less formal documentation processes.

Functional Requirements

Functional requirement statements “define the fundamental actions that must take place” (IEEE, 1998, p. 16) in the software system. Additionally, they provide detailed information on how a system should perform and how it should interact with databases and other systems, but do not address user interaction or business value. Detailed design constraints and compliance standards the system must meet are also included in functional requirement statements. Figure 1 provides an example of a functional requirement statement used on the GCSS-Army project. This example was taken from the GCSS-Army requirements database.

**FIGURE 1. EXAMPLE OF A FUNCTIONAL STATEMENT OF
REQUIREMENTS EXTRACTED FROM THE
GCSS-ARMY REQUIREMENTS DATABASE**

The system shall allow a user to enter mission and/or usage data.

Source for requirement: ULLS-G—P3-29(1) FD, ULLS-G EM 7.2.3

The example in Figure 1 is a simple one; however, Cohn (2004a) suggests that typical IEEE-style functional requirement statements are “time consuming to write and read, assume everything is known in advance” (p. 5), and lack early user feedback. Functional requirement statements are typically listed as “shall statements,” where each requirement starts with “the system shall...” (p. 16). A functional requirement typically includes elements such as:

- Validity checks on the inputs;
- Exact sequence of operations;
- Responses to abnormal operations;
- Effect of parameters; and
- Relationship of outputs to inputs (IEEE, 1998, p. 16).

Functional requirement statements are rolled up into a single “software requirements specification (SRS) document” (IEEE, 1998, p. 4). A typical SRS describes all of the system’s technical and functional specifications for products and systems. Paetsch et al. (2003) indicated that the SRS is “unambiguous, complete, correct, understandable, consistent, concise, and

feasible” (p. 3). Software requirements specification documents are typically provided to a program management office as the “baseline” (Paetsch et al., p. 3) as input into a “linear waterfall development activity” (Davies, 2001, p. 46) “before analysis starts” (Jacobson, Spence, & Bittner, 2011, p. 16). Jacobson et al. (2011) further suggested that requirements analysis “starts before implementation,” and implementation is completed before the “verification starts” (p. 16), leaving user feedback out of the process until all development and testing has been completed, which is not conducive to iterative SDLCs.

Use Case

An approach used in both traditional and interactive software development projects to describe system requirements is the use case. Use cases allow analysts to solicit and document requirements from the customer with the goal of identifying and describing a number of “typical use cases for every actor” (Regnell et al., 1995, p. 1) interacting with the system. The use case is a component of the Unified Modeling Language, which supports iterative software development processes, thereby allowing an analyst to solicit user feedback early in the development cycle.

Additionally, a use case defines all of the ways of “using a system to achieve a particular goal for a particular user” (Jacobson et al., 2011, p. 4) and “describes the possible outcomes of an attempt” (International Institute of Business Analysis, 2015, p. 398) to accomplish that goal. Additionally, a use case makes it “clear what a system is going to do and, by omission, what it is not going to do” (Jacobson et al., p. 4).

Wiegiers and Beatty (2013) provided an example of using use cases in gathering the requirements for a “Chemical Tracking System” (p. 161) in an iterative environment. The researchers suggested that in an iterative environment, waiting until the “requirements specification is complete” (p. 161) is too late to seek user feedback, and suggest that soliciting early and consistent feedback from users is a key success factor in documenting requirements in an iterative SDLC. This is a key difference in iterative processes and traditional processes. For example, Paetsch et al. (2003) conducted a study that compared traditional requirements-engineering methods, use cases, and Agile software development approaches. These researchers indicated that customer involvement was a primary difference between the different methodologies, which can be beneficial to the success of a software development project.

Additionally, use cases are written from the user’s perspective to “avoid describing the internal workings of the system” (International Institute of Business Analysis, 2015, p. 398) and are very detailed. According to the institute, there is “no fixed, universal format” (p. 398) for creating a use case. However, Wiegers and Beatty (2013) recommended the use of a template in the form of a Microsoft Word document or spreadsheet with a formal organization. A use case has certain elements that are considered mandatory, which are listed in Table 1.

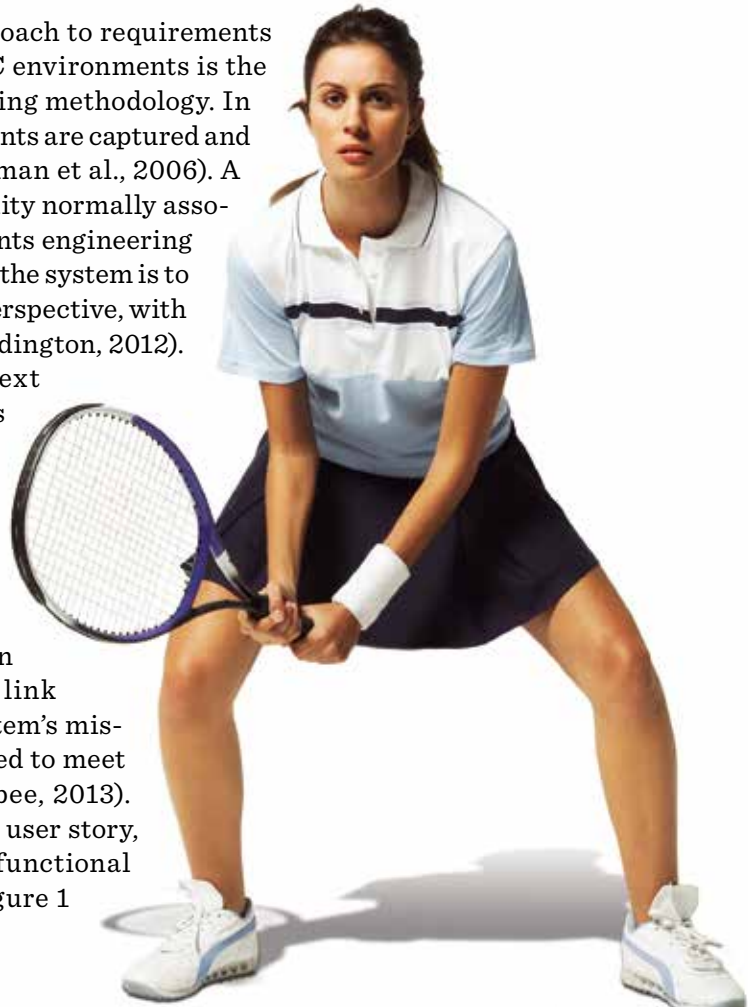
TABLE 1. MANDATORY ELEMENTS OF A USE CASE		
Element	Description	Prior Research
Name or ID	The unique name of the use case.	International Institute of Business Analysis, 2015; Wiegers & Beatty, 2013
Goal	Brief description of a successful outcome.	International Institute of Business Analysis, 2015
Primary Actor or Actor	A person or external system that interacts with the system.	International Institute of Business Analysis, 2015; Wiegers & Beatty, 2013
Preconditions	Any fact that must be true before the use case can begin, which acts as a constraint on its execution.	International Institute of Business Analysis, 2015
Post Conditions; Guarantee	Any fact that must be true for all possible primary and alternative flows when the use case is complete.	Wiegers & Beatty, 2013
Trigger	An event that initiates the flow of events for a use case.	International Institute of Business Analysis, 2015; Wiegers & Beatty, 2013
Exceptions	Any exceptions/messages that must be handled by the system.	Wiegers & Beatty, 2013
Flow of Events	The activities performed by the actor and the system during the use case’s execution.	International Institute of Business Analysis, 2015

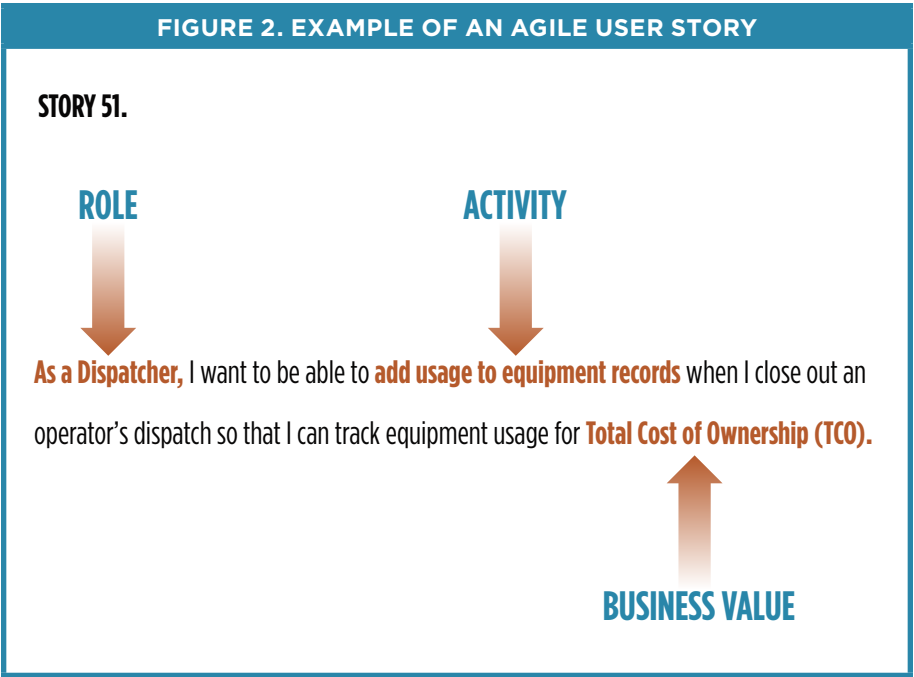
Use cases have some advantages and limitations. For example, Regnell et al. (1995) suggested use cases help deal with the “complexities of the requirements analysis process” by allowing customers and developers to

“focus on one, narrow aspect of system usage at a time” (p. 1). Lee, Cha, and Kwon (1998) added that use cases are easy to “describe and understand and are scalable” (p. 1), allowing the customer to trace use cases throughout the SDLC. Like Wiegers and Beatty (2013), Regnell et al. (1995) indicated that one advantage of the use case is that it facilitates active collaboration between the customer and developer, which enables the developer to learn about “potential users, their actual needs, and their typical behavior” (p. 1). However, they further indicated this approach can produce a “loose collection of use cases, which can lack ‘synthesis’” (p. 1), which is a weakness. Lee et al. (1998) identified the “lack of rigor” and no “systematic approaches to analyzing dependencies” among the many use cases developed for a system, which impedes “detecting flaws” (p. 1), as limitations to this approach.

User Stories

Another well-known approach to requirements engineering in iterative SDLC environments is the Agile requirements-engineering methodology. In an Agile SDLC, user requirements are captured and recorded as user stories (Layman et al., 2006). A user story removes the formality normally associated with typical requirements engineering activity. They still define what the system is to perform, but from the user’s perspective, with a focus on business value (Saddington, 2012). User stories provide a context within which a requirement is to be developed around some “feature, functionality, or capability needed” (Coplien & Bjørnvig, 2011, p. 167). User stories provide a more effective means by which the customer, in coordination with the program office, can link a user requirement to the system’s mission-critical functions required to meet organizational goals (Huckabee, 2013). Figure 2 provides an example user story, which is a conversion of the functional requirement statement in Figure 1 to an Agile user story.





Note. This user story was created from the functional Statement of Requirements shown in Figure 1.

Wiegers and Beatty (2013) suggested that user stories are concise statements that “articulate user needs and serve as a starting point” (p. 144) for customer and developer collaboration. Use cases are different from functional requirement statements, which focus on a single system task. User stories are an “interaction” (Nazzaro & Suscheck, 2010, p. 2) between the user and the system, focusing on business value. User stories are written or told from the “perspective of the person who needs the new capability” (Wiegers & Beatty, 2013, p. 145). They are informal and written in plain English on an index card. User stories typically describe a process or process step, focusing on a user role (or another system), which performs the process and achieves the business value. User stories can also be broken down into “quantifiable units of development effort” (Breitman & Leite, 2002, p. 3), which can increase the accuracy of estimating scope.

User stories identify critical success factors used to measure system performance during development. However, to be effective, the format of user stories must follow standards in their creation, use, and interpretation. Table 2 describes user story components.

TABLE 2. ELEMENTS OF A USER STORY		
Element	Description	Prior Research
Title	Story title	International Institute of Business Analysis, 2015; Rees, 2002
User story number or ID	Unique identifier of the requirement	Rees, 2002
Value statement	Value achieved from the capability	International Institute of Business Analysis, 2015; Nazzaro & Suscheck, 2010; Rees, 2002
Conversation or activity	Action being performed by the system; aids in understanding the features and/or values to be delivered	International Institute of Business Analysis, 2015; Nazzaro & Suscheck, 2010; Rees, 2002
Related story numbers	Relates the current story to other stories	Rees, 2002
Acceptance criteria	Defines the boundaries of the capability; describes system specifications	International Institute of Business Analysis, 2015; Koch, 2005; Leffingwell & Widrig, 2003; Resnick, Bjork, & de la Maza, 2011; Sy, 2007

The most important feature of a user story is its use in promoting collaboration between the customer and software development team about a need or needed capability. Storytelling is a major part of the process where the customer tells a story about a user’s need or capability with some acceptance criteria. Cao and Ramesh (2008) conducted a qualitative study of 16 organizations using Agile requirements-engineering processes. They suggested that using user stories in an Agile-based software program creates a more satisfactory relationship between the customer and developer. As iterations of storytelling and demonstrations continue, the requirements will change until all acceptance criteria have been demonstrated and accepted by the customer, tested, and promoted to the production system. Cao and Ramesh also suggested that in an Agile environment, user stories produce “clearer and more understandable” requirements because of the “immediate access to the customer” (p. 64). Leffingwell and Widrig (2003) agree and suggest that when the software developer misunderstands or misinterprets customer needs, trust is reduced, which can result in the “inability of the program manager to resolve budget and schedule conflicts” (p. 782).

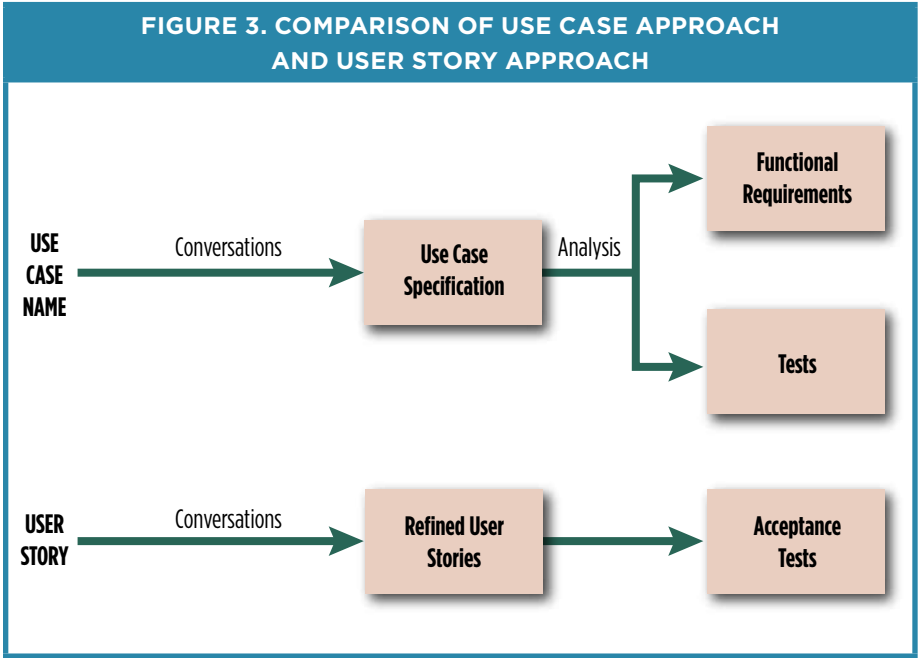
Acceptance criteria accompany each user story and are defined when the user story is created. Acceptance criteria define when development is complete (Resnick et al., 2011), and when a story is added to a sprint the acceptance criteria can be adjusted. This is where the customer communicates system specifications to the development team. Unlike user stories, acceptance criteria have no defined content or format (Figure 2). However, Nazzaro and Suscheck (2010) suggested that acceptance criteria can be a “test case or a brief description of ‘done’” (para. 11). Also, acceptance criteria must be clearly understood by all parties, as it helps in establishing a shared understanding of success. A story’s acceptance criteria should include usability requirements, specific performance metrics, and data validation requirements. Including these components in acceptance criteria assists the customer in defining measurable and testable criteria (Koch, 2005; Leffingwell & Widrig, 2003; Sy, 2007).

Acceptance criteria that are too detailed can limit collaboration and result in a misinterpretation of a requirement, whereas acceptance criteria with little detail create a scenario where a requirement is missed. The right mix of acceptance criteria will become clear with experience; however, best business practices dictate that not all the details need to be included in the acceptance criteria for a given story. For example, this article suggests that more details about a need or capability can be provided as an attachment, such as a mock-up, spreadsheet, and/or algorithm, and additional criteria can be placed in integrated test cases for validation later in the development cycle (Leffingwell & Widrig, 2003; Nazzaro & Suscheck, 2010; Resnick et al., 2011).

A Comparison of Use Case and User Stories

Requirements engineering literature reveals that use cases and Agile user stories are both advantageous in iterative SDLCs; however, some differences exist. Both use cases and user stories initiate a dialogue with the customer about the desired capability and are both “sized to deliver business value” (Cohn, 2004b, para. 14). Davies (2001) suggested the primary differences between the two methodologies are in the way “their scope is determined” (p. 46) and the artifacts produced during the requirements gathering activities, as well as “consistency” (p. 48). Nazzaro and Suscheck (2010) suggested the primary difference is that use cases communicate system capabilities, while the user story focuses on “customer value” (para.

16). The use case is more formal and detailed, whereas user stories are less formal. The deliverables or artifacts produced using the two approaches vary (Figure 3). Wiegers and Beatty (2013) described these as a “core distinction” (p. 146), which aligns with Davies (2001) in that the artifacts produced from the use case approach include a “use case model, a design model, software development plan, software components, and a test plan and test cases” (p. 48).



Note. Adapted from Wiegers and Beatty, 2013, p. 146. Copyright 2013 by Karl Wiegers and Seilevel. Reprinted with permission.

Davies (2001) suggested that user stories are less formal and written on an index card, and the artifacts produced using user stories are a “story card, engineering tasks, source code with associated unit tests, and acceptance tests and a software release” (p. 48). This aligns with Cohn (2004a) and Wiegers and Beatty (2013) in that user stories are “smaller in scope” (para. 14) than use cases.

The use case methodology is more consistent than the user story methodology because the goal behind use cases is to provide a complete set of requirements documents, whereas “gaps can emerge” when using Agile stories because the development activities in a sprint reflect only “those requirements discussed with the customer” (Davies, 2001, p. 48); it is the

customer's responsibility to ensure that any gaps in requirements are identified during the demonstration of the software at the end of each sprint. However, Nazzaro and Suscheck (2010) would disagree; they suggest that the higher level of collaboration between the customer and developer using Agile stories produces a higher level of detail than use cases.

Finally, both methods define the boundaries on what is expected to be delivered and define when development is done, as well as help to establish process objectives and thresholds, such as screen refresh rate, printing times, or exporting formats. The detailed nature of use cases is good at "articulating the functional behavior of a system" (p. 401). In contrast, user stories are good in helping to "capture stakeholder needs" and prioritizing development activities, and they serve as a good basis for estimation and project planning, WBS development, requirements traceability, and for "project reporting" (International Institute of Business Analysis, 2015, p. 402).

GCSS-Army Requirements-Engineering Overview

Requirements engineering activities on the GCSS-Army program have changed over the past 5 years. When the program began, requirements engineering activities followed the waterfall SDLC, where a number of requirements in a functional specification document (database version) were handed over to the developer for planning, analysis, and development. These requirements were in the form of functional requirement statements (Figure 1) that defined system operation. The program started with over 8,000 functional requirement statements; however, because of program rescoping activities, the requirements were reduced to just over 4,500. These functional requirement statements limited the program's abilities to interpret the requirements, because many lacked the important business rules required to fully develop a specified capability. Moreover, the functional requirement statements contained limited test criteria; experience from Army logistics subject matter experts was relied upon to develop test criteria to validate requirements, which constrains incremental development.

Often, these functional requirement statements failed to tie system activity to business value or to the organizational goals that users expected, possibly limiting the system's benefits once deployed. Also, functional requirement statements do not allow for change, which is the norm in incremental SDLC activities. In typical incremental activities, requirements are modified during development based on the customer's priorities during a sprint.

Most of the functional requirements found in the Combined Arms Support Command's GCSS-Army requirements database originated from antiquated software end-user manuals of systems no longer in service. For example, the functional requirement statement in Figure 1 was extracted from the Unit Level Logistics System–Ground end-user manual. The replacement of this system began in the mid-1990s with the Standard Army Maintenance System–Enhanced (SAMS-E). Additionally, functional requirement statements such as Figure 1 were never purged or updated. The antiquated statements may still be valid; however, many of the statements are not connected to regulatory guidance and are not process-oriented, which reduces the effectiveness of Business Process Reengineering (BPR). This disconnect adds complexity and error to the planning, analysis, and development processes and can add risk in a compressed development timeline. This can also result in the fulfillment of a requirements list, instead of focusing on delivering capabilities that add business value, or that can be linked to organizational goals (Saliu, 2005). Finally, to overcome these limitations, the Program Manager (PM) GCSS-Army mandated a change in the acquisition strategy for production release 1.1 and beyond.

The Agile methodology is aimed at increasing productivity, reducing requirement volatility, increasing customer satisfaction, and improving software quality focusing on incremental development (Maurer & Martel, 2002).

In 2009, PM GCSS-Army directed the systems integrator to depart from the waterfall SDLC and adapt the Agile SDLC methodology. Background data supporting the move to the new methodology indicated productivity issues, requirements volatility, and the need for rapid prototyping to meet program scope, schedule, and budget constraints. The Agile methodology is aimed at increasing productivity, reducing requirement volatility, increasing customer satisfaction, and improving software quality focusing on incremental development (Maurer & Martel, 2002). During this change, analysis of functional requirement statements ceased and user stories became the standard for GCSS-Army requirements, introducing new challenges for the program.

Even though the program provided Agile training to project members, moving from functional requirement statements to Agile user stories was a paradigm shift. With this shift, the program office had not established standards for user story development. Without a standard, customers developed user stories with no specific format or criteria by which to validate what was to be delivered. This created an atmosphere where the customer and developer lacked a shared understanding of what defined success with regard to a capability's specification or how user stories were to be interpreted. This lack of understanding of story structure, content, and format created increased requirement volatility in the Wave 1 product release, which started with an approved requirements baseline of just 200 user stories. The volatility in Wave 1 generated over 300 change documents, either modifying existing requirements, or adding requirements that were missed.

By applying best practices to what has been learned about the Agile methodology over the past 5 years to current and future development efforts, a standardized process for creating user stories and associated acceptance criteria can be created. Standardized processes for creating user stories will increase the customer's ability to develop measurable and testable user stories; increase the effectiveness of the systems integrator's planning, analysis, and development activities; reduce the negative impact on the program's scope, cost, and schedule; and deliver a quality product that meets the customer's expectations. These benefits align with findings by Cao and Ramesh (2008) that Agile requirements engineering can "produce clearer and more understandable requirements" (p. 64), with capabilities that are more aligned with the customer needs and can be better prioritized as the customer's needs change.

Best business practices also dictate that a link to other stories be placed in the acceptance criteria. Linking the current story and acceptance criteria to other requirements helps the PM keep scope creep to a minimum. Lessons learned from the GCSS-Army program indicate that the development of one story can impact other stories; therefore, a link is required to reduce the amount of rework or defects later in the SDLC. Additionally, this link provides integration points to existing stories or stories that have not been created. This link is necessary to ensure requirements are completely integrated into the enterprise solution, and it helps in integration and regression testing later in the development cycle. For example, in Figure 4 the Dispatcher role does not track the total cost of ownership, but the role does contribute to the business objective, which adds value for the Army.

With the addition, in the acceptance criteria, of two sentences that link to other stories (roll-up of usage data), a customer can prevent scope creep, errors, and defects downstream in development.

FIGURE 4. EXAMPLE ACCEPTANCE CRITERIA TAKEN FROM GCSS-ARMY REQUIREMENTS TRACEABILITY MATRIX

ACCEPTANCE CRITERIA

Demonstrate that GCSS-Army will 1) allow me to update usage on an end item when a Dispatch is closed 2) allow me to update usage on components when a Dispatch is closed 3) allow me to view the total usage on an end item and/or components 4) demonstrate that equipment usage is provided to LOGSA through the backwards compatibility interface currently in production.

Link to other stories:

No roll-up of usage by equipment category or equipment serial number is needed now (another story).
No roll-up of usage by component is needed now (another story). (POC Jane Smith).

Story Controls:

AR 750-1, DA Pam 738-751, and DA Pam 750-8

Note. AR = Army Regulation; DA = Department of the Army; LOGSA =Logistics Support Activity; Pam = Pamphlet; POC = Point of Contact.

Lessons learned from previous development activities would indicate that some form of controls be placed on Agile requirements and that such controls become a best practice in the development of Agile requirements. Story controls define the boundaries for an Agile requirement. These controls are found in the Army Integrated Logistics Architecture (U. S. Army, 2008) as inputs to operational activities. Story controls consist of Army Regulations, a Department of the Army pamphlet, and field manuals. These controls connect the Agile requirement to the logistics architecture, establish references to the as-is processes, and aid in BPR. Additionally, story controls assist the customer and developer in demonstrating where a software solution can fill capability gaps and in identifying the policy implications brought on by BPR. Controls facilitate the customer’s dialogue with the logistics and tactical finance communities on required policy changes. Finally, story controls

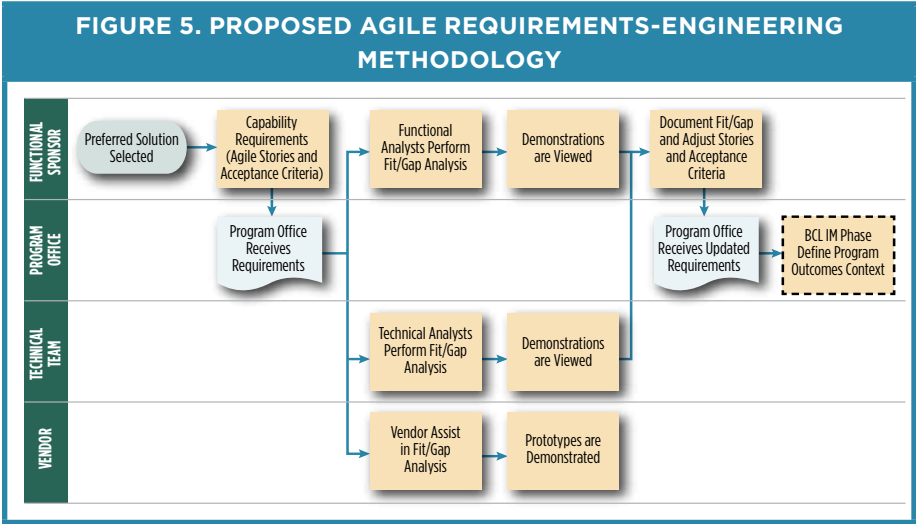
benefit the program by providing a shared understanding of specific regulatory requirements, facilitate policy updates and requisite business rules, and prevent scope creep.

Refining Agile Requirements

The BCL methodology provides a 12-month block of time between Milestones A and B, when program planning occurs. This is when Agile requirements can be refined and become part of the potential program scope and approach documentation, which is part of the prototyping phase. At this point, the sponsoring organization should coordinate with the program office to provide a technical team to work with the functional sponsor in reviewing and refining the requirements through product demonstrations and prototyping. These actions align with findings by Cao and Ramesh (2008) that a benefit of prototyping allows the customer to “validate and refine requirements” to obtain “quick customer feedback” (p. 65). This is an important step that must not be overlooked. For example, performing this analysis enables the technical team to determine how a product can fulfill requirements with out-of-the-box capabilities, limiting the amount of customization required to fulfill the user’s requirements, which is one of the goals of the BCL methodology. During the refinement process, the technical team works with the functional sponsor to review requirements; provide specific solutions and recommendations based on requirement analysis, product demonstrations, prototyping, and simulations; and document the solutions’ fit/gap. In this study, a fit/gap analysis is the method of comparing as-is “enterprise processes and system functions to adapt local processes to industry best practices” (Pol & Patukar, 2011, p. 2) contained in a software solution. A fit/gap can be performed by different methods; among them are demonstrations, or what Pol and Paturkar defined as “simulations” (p. 2). Once the fit/gap analysis is complete, user stories and acceptance criteria are modified to address the solutions’ fit/gap with the user’s requirements. This final step reduces program scope and schedule risk by providing the systems integrator with a list of refined requirements for estimation and development.

From a BCL process perspective, the fit/gap analysis should be initiated once the preferred solution has been identified and serve as an input into the Define Program Outcome context. This is because during the business process reengineering activities, the functional sponsor has gained an understanding of the processes to be implemented into the software solution. The outcome of this process should be a set of reengineered process

models with known requirements and potential gaps. Figure 5 describes the proposed Agile requirements-engineering methodology as it relates to the BCL process (DAU, 2013).

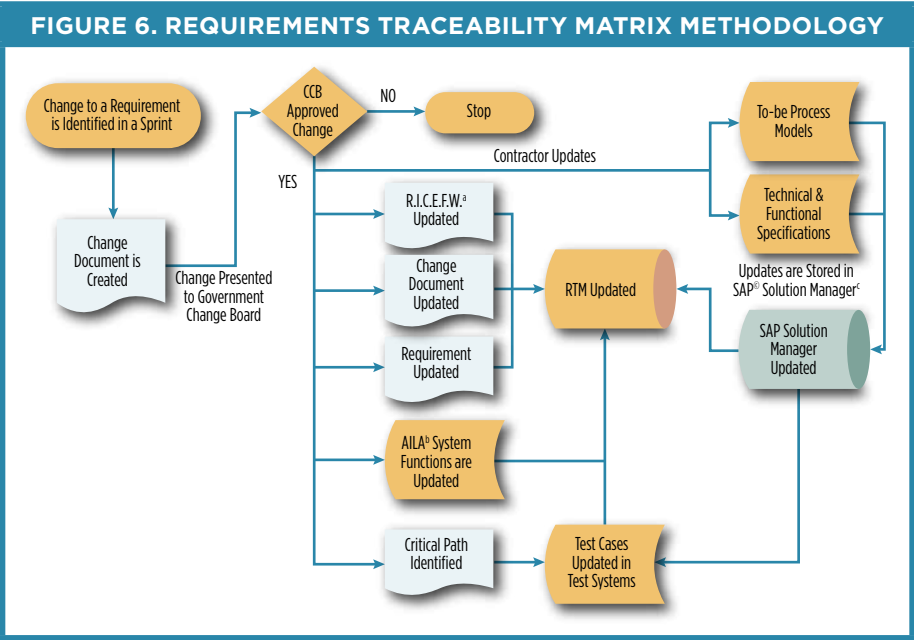


Once the requirements and gaps are identified, the technical team, functional sponsor, and vendor work together to analyze the requirements to demonstrate how the solution can fulfill the requirements and analyze potential gaps to determine whether the solution can fulfill the gaps without customization. The fit/gap results are annotated and the Agile requirements are updated to reflect the new information. The annotated results and updated requirements are then handed off to the program office as input into the Define Program Outcome context (DAU, 2013).

Managing Requirements during Development

One of the most difficult tasks of an Agile project is tracking changes to the Agile requirements baseline. This need for tracking is common on Agile projects, as most requirements generated in the requirements engineering process can be modified based on the customer’s priorities while in a sprint. From a capabilities development perspective, lessons learned on the GCSS-Army project show that requirements management and traceability are difficult challenges. To address this challenge and reduce requirement volatility, the PM GCSS-Army has created tools and

a methodology to manage requirement changes and traceability using an online Requirements Traceability Matrix (RTM), as well as commercial software packages used to track requirements as development objects move through the development landscape. The process flow in Figure 6 describes the methodology used to create the online RTM. Because of the iterative nature of an Agile SDLC, the methodology is a critical component of an Agile acquisition project as large as GCSS-Army, and more emphasis must be placed on this process to ensure that user requirements implemented in the solution meet the sponsoring organization’s needs.



Note. CCB = Change Control Board; ªR.I.C.E.F.W. = R-Report; I-Interface; C-Conversion; E-Enhancement; F-Form; W-Workflow. Each of these objects is a development object. ºAILA = Army Integrated Logistics Architecture; ºSAP Solution Manager = Systems, Applications and Products Solution Manager.

Proposed Benefits

In addition to the benefits mentioned earlier, implementing the best practices and lessons learned presented in this article will generate advantages for a BCL program. Some of the benefits that can be realized from a more elaborate requirements engineering process include: (a) increased effectiveness in meeting user needs; (b) increased performance of customer and software developers; (c) reduced requirements volatility; (d) a defined

functional and technical scope baseline to be included in the contract documentation at Milestone B; (e) less uncertainty in the estimation process; (f) the potential for a standardized process that can be used DoD-wide; and (g) increased customer satisfaction. Finally, these benefits provide the justification for PMs to use the best business practices recommended in this article.

Conclusions

Change in the requirements engineering processes is required to ensure the success of a BCL-based defense business system development activity. This change is required in part because the BCL approach depends on an accurate and prioritized list of Agile requirements and accurate program scoping so as to facilitate a focus on fielding usable business capabilities as quickly as possible (DAU, 2013, p. 12). Accurate Agile requirements engineering provides the foundation for a successful BCL program because it is more receptive to change. Using story controls establishes the boundaries of the requirement, potential process objectives, and thresholds, and promotes understanding and communication between the customer and developers. Using a standardized and elaborate requirements-engineering process following the Agile software development methodology to develop and refine requirements can provide significant benefits. Finally, following best business practices will help in reducing uncertainty and requirement volatility, thus increasing the chances of success in the short cycle time mandated by the BCL methodology.

Following best business practices will help in reducing uncertainty and requirement volatility, thus increasing the chances of success in the short cycle time mandated by the BCL methodology.

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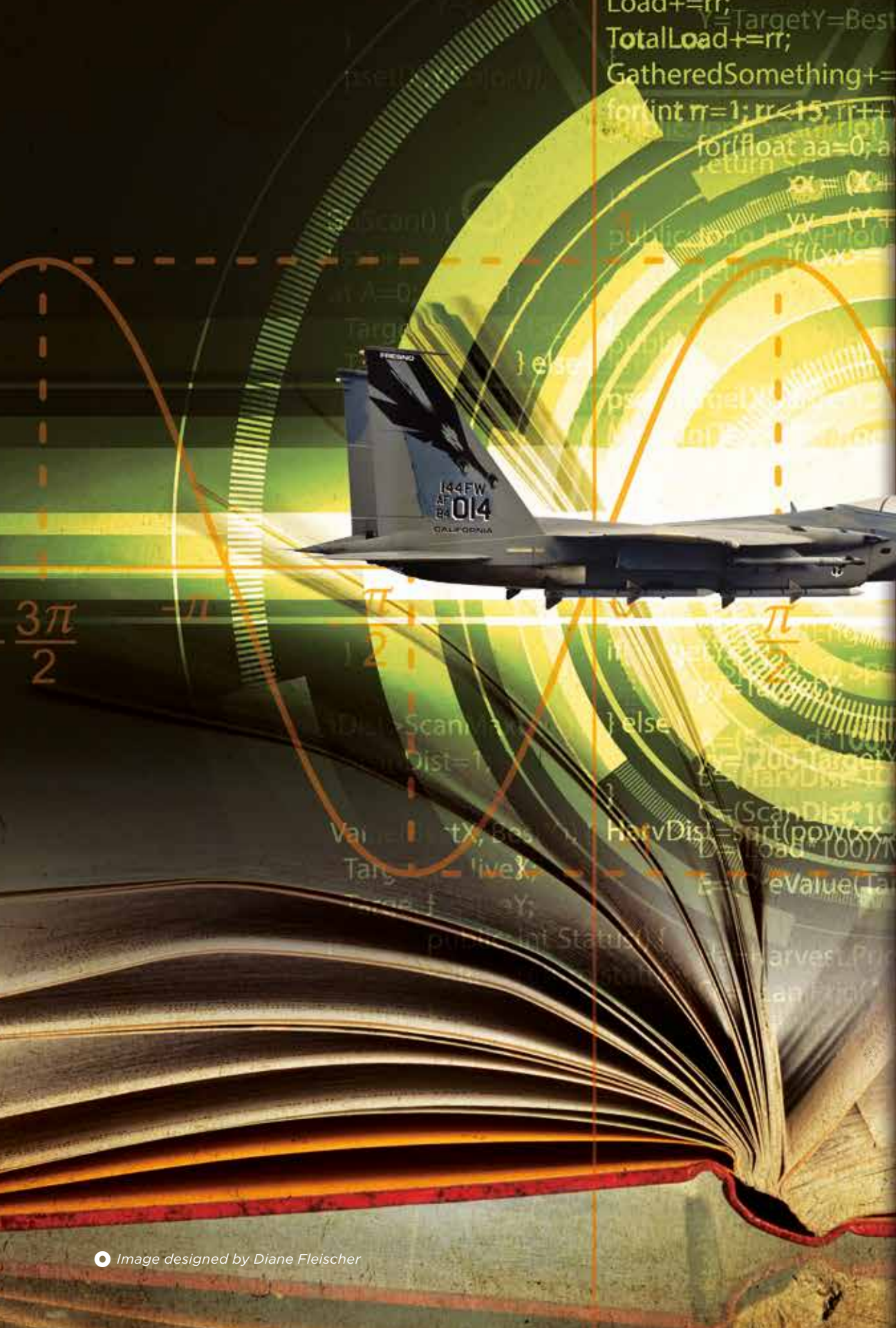
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Biography




Dr. W. Allen Huckabee is a consultant with LMI providing technical expertise to the test director of Global Combat Support System-Army at Fort Lee, Virginia. Dr. Huckabee provides support to ensure the acquisition program is effective and suitable for combat use. Before joining LMI, he served as a capability developer for GCSS-Army. Dr. Huckabee earned his MBA in Business Management from Saint Leo University and his PhD in Organization and Management with Specialization in Project Management from Capella University.

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ACQUISITION CHALLENGE: The Importance of INCOMPRESSIBILITY in Comparing Learning Curve Models

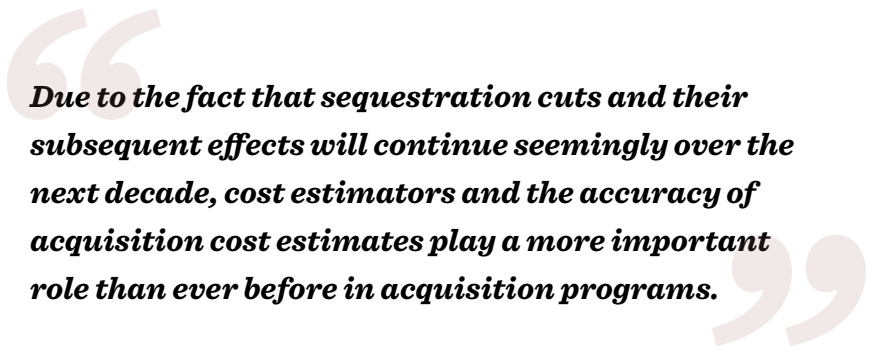
 *Capt Justin R. Moore, USAF, John J. Elshaw, Adedeji B. Badiru, and Lt Col Jonathan D. Ritschel, USAF*

The Department of Defense (DoD) cost estimating methodology currently employs T. P. Wright's 75-plus-year-old learning curve formula. The goal of this research was to examine alternative learning curve models and determine if a more reliable and valid cost estimation method exists, which could be incorporated within the DoD acquisition environment. This study tested three alternative learning models (the Stanford-B model, DeJong's learning formula, and the S-Curve model) to compare predicted against actual costs for the F-15 A-E jet fighter platform. The results indicate that the S-Curve and DeJong models offer improvement over current estimation techniques, but more importantly—and unexpectedly—highlight the importance of incompressibility (the amount of a process that is automated) in learning curve estimating.

Keywords: *cost estimation, Stanford-B, DeJong, S-Curve, Wright's Learning Curve, learning curve*

In 2008, the U.S. economy took a plunge that affected every industry from the real estate market to automobile manufacturers. This crash led to tightened budgets throughout the country, and many companies looked to operate more efficiently with less capital. That economic turmoil is reflected in the Department of Defense (DoD) through funding cuts and shrinking budgets at every level. The Budget Control Act of 2011, approved by Congress, places emphasis on commanders and managers using funds more efficiently.

On a micro level, the scrutiny of program cost estimates places more pressure on estimators than ever before. Due to the fact that sequestration cuts and their subsequent effects will continue seemingly over the next decade, cost estimators and the accuracy of acquisition cost estimates play a more important role than ever before in acquisition programs. Cost estimates are no longer just a box to check at milestone reviews; they now provide leverage for managers and valuable information in balancing budgets.



Due to the fact that sequestration cuts and their subsequent effects will continue seemingly over the next decade, cost estimators and the accuracy of acquisition cost estimates play a more important role than ever before in acquisition programs.

Background

The Budget Control Act of 2011, which calls for a \$1.5 trillion deficit reduction over the next 10 years, has created a fiscally constrained environment in which competition for congressional funding is higher than ever before. On an organizational level, DoD acquisition programs have seen budget cuts up to 10 percent, changes in acquisition schedule, reduction in the number of systems purchased, and an increased scrutiny over cost estimates.

One way to assist cost estimators, and consequently decision makers, is to provide them with the most current and appropriate tools to calculate accurate and reliable predictions. However, conventional learning curve methodology has been in practice since the pre-World War II build-up in the 1930s, and those historical techniques may be outdated in today's fast-paced, technological environment.

Over the past two decades a new methodology, rooted in the concept of forgetting curves, has emerged and may provide a more accurate tool for assessing learning curves. Forgetting is becoming more widely accepted, but its application to learning curves in manufacturing is scarce. This research will incorporate contemporary learning curve models to cost estimates within large DoD acquisition programs.

The concept of learning and the application of learning curves are widely used in everything from industrial manufacturing to avionics software development. The footprint of the learning phenomenon applies throughout both public and private business sectors. In recent years, the concept of forgetting has been introduced, which unlike Wright's (1936) model, does not assume a constant learning rate. Learning curves are widely used and even expected throughout the DoD cost estimating community. Air Force guidance on learning curve theory and application primarily originates from the *Air Force Cost Analysis Handbook* (AFCAH, 2008), Chapter 8. This resource primarily focuses on two learning curve theories: unit theory and cumulative average theory. This research does not intend to discredit the use of learning curves, but rather incorporates and assesses contemporary methodology within the confines of major acquisition programs.

Theory Review

Learning curve models came into use by manufacturing practitioners in the late 1930s. At the height of the pre-World War II build-up, aircraft production costs were as important as developing and producing the aircraft themselves. T. P. Wright (1936) first identified the existence of the learning relationship. He correctly theorized that as a worker performs the same task multiple times, the time required to complete that task will decrease at a constant rate. The workers are learning from previous experience and thus becoming more efficient in completing the task. Wright also identified the *80 percent learning effect* in aircraft production. He believed that organizations would observe a learning rate of 80, or a 20 percent production

improvement, as the number of units produced doubled (Wright 1936). This rule has been changed and modified over time to fit different applications; however, it remains the standard in many industries.

While a vast collection of theory and studies exists relating to learning curves, very little attention has been given to the performance degradation due to the impact of forgetting (Badiru, Elshaw, & Everly, 2013). We define forgetting as the process of unlearning and the loss of knowledge, particularly through the passage of time. Forgetting is simply the concept that workers will inevitably see a decline in performance (from many potential sources) while still theoretically moving along the learning curve (Badiru, 1995). The incorporation of forgetting is a critical piece of learning curve theory because it helps explain variance in the process that otherwise may be unaccounted for.

Forgetting is simply the concept that workers will inevitably see a decline in performance (from many potential sources) while still theoretically moving along the learning curve (Badiru, 1995).

The classical learning curve model, often referred to as Wright's Learning Model, gives mathematical representations of Wright's basic learning theory. The model shown in Equation (1) follows the assumption that as the quantity produced doubles, the cost will decrease at a constant rate.

$$T_x = T_1 x^b \quad (1)$$

Where:

T_x = the cumulative average time (or related cost) after producing x units

T_1 = hours required to produce (theoretical) first unit

x = cumulative unit number

$$b = \log R / \log 2 = \text{learning index}$$

Note: R in the term above = learning rate (a decimal)

J. R. Crawford (1944) adopted a similar learning curve approach in the *individual unit* model that he introduced in a training manual at Lockheed Martin. Crawford's model uses the same basic formula as Wright's model, but attempts to estimate *individual* times (or related cost) to produce a given unit by changing which variables are input into the model.

Both unit theory and cumulative average approaches are used in acquisition cost estimating, depending on the amount and validity of historical program data. However, contractor reports often come in the form of lots. This form of data is usually more advantageous when using a cumulative average learning curve. The DoD Basis of Cost Estimating illustrates how such data can be used as a lot average in the cumulative average learning curve theory rather than finding a theoretical lot midpoint as with the unit theory (DoD, 2007).

[A]pply the Cum Avg formulation to contractor lot information, add the hours/costs for a given lot to the hours/costs of all previous lots. The hour/cost plot value (Y axis) of a given lot is the total hours/costs through that lot divided by the last unit number of that lot, while the unit plot point (X axis) is the last unit number of that lot. Lot midpoints are not used with the Cum Avg formulation. (p. 8-21)

Furthermore, Hu and Smith (2013) identify a method for plotting and predicting learning curves using lot data, "If the cumulative average costs for all consecutive lots are present, then the direct approach can be applied to the lot data with the last unit in the lot as the lot plot point (LPP)" (p. 28). This LPP is the same as the unit plot point described in the AFCAH and provides a means for plotting lot data against individual units (on the X axis) to determine the learning parameters. Hu and Smith describe this process saying, "T1, b, and other exponents can be obtained directly from the ordinary least squares (OLS) method by regressing [cumulative average costs] vs. cumulative quantities" (p. 28).

Since Wright's initial theory, several other models have been adopted in learning curve literature. One of the earliest modifications to the learning curve model came along with introduction of the Stanford-B model shown in Equation (2).

$$T_i = T_1 (x + B)^{-b} \quad (2)$$

Where:

T_i = the cumulative average time (or related cost) after producing x units

T_1 = hours required to produce (theoretical) first unit

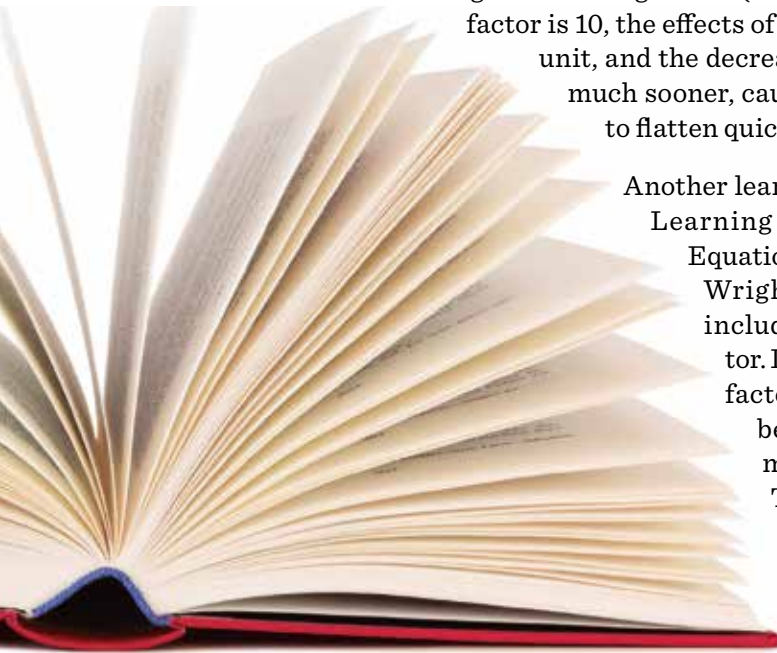
x = cumulative unit number

$b = \log R / \log 2$ = learning index

B = equivalent experience units (a constant); slope of the asymptote of the curve.

This model is attributed to Louis E. Yelle (1979) during a government-funded research initiative at Stanford. It introduces the equivalent experience unit parameter to Wright's original equation. This parameter, represented by B , is a constant from 0 to 10, accounting for the number of units produced prior to start of production of the first unit, and is the slope of the asymptote of the learning curve. If this factor is 0, the model reverts to Wright's original learning model (Badiru, 2012). Conversely, if the factor is 10, the effects of learning will begin at the 11th unit, and the decrease in performance will occur much sooner, causing the learning curve slope to flatten quickly.

Another learning curve model is DeJong's Learning Formula. DeJong's model in Equation (3) is also a derivation from Wright's original function, which includes an incompressibility factor. Denoted by the constant M , this factor represents the relationship between manual processes and machine-dominated processes. The incompressibility factor is



a constant between 0 and 1, in which a value of 0 implies a fully manual operation and a value of 1 denotes a completely machine-dominated operation (Badiru et al., 2013).

$$T_x = T_1 [M + (1 - M)x^{-b}] \quad (3)$$

Where:

T_i = the cumulative average time (or related cost) after producing x units

T_1 = hours required to produce (theoretical) first unit

x = cumulative unit number

$b = \log R / \log 2$ = learning index

M = incompressibility factor (a constant)

Wright's original model, which inherently assumes an incompressibility factor of 0, fails to account for a major percentage of the production industry that uses automated manufacturing technology.

The S-Curve model accounts for both the prior experience and incompressibility factors together. Carr (1946) believed that there was an error in Wright's constant learning assumption and hypothesized that the effects of learning and thus performance followed the S-Curve shape. The S-Curve model assumes a gradual build-up in the early stages of production followed by a period of peak performance. This build-up is typically attributed to personnel and procedural changes as well as time needed for new machinery set-ups that occur early in the production process. Towill and Cherrington (1994) used the theory hypothesized by Carr to develop a model that follows an S-shaped pattern. The S-Curve model shown in Equation (4) assumes that learning takes the S-shaped curve often seen in a cumulative normal distribution.

$$T_x = T_1 + M(x + B)^{-b} \quad (4)$$

Where:

T_i = the cumulative average time (or related cost) after producing x units

T_1 = hours required to produce (theoretical) first unit

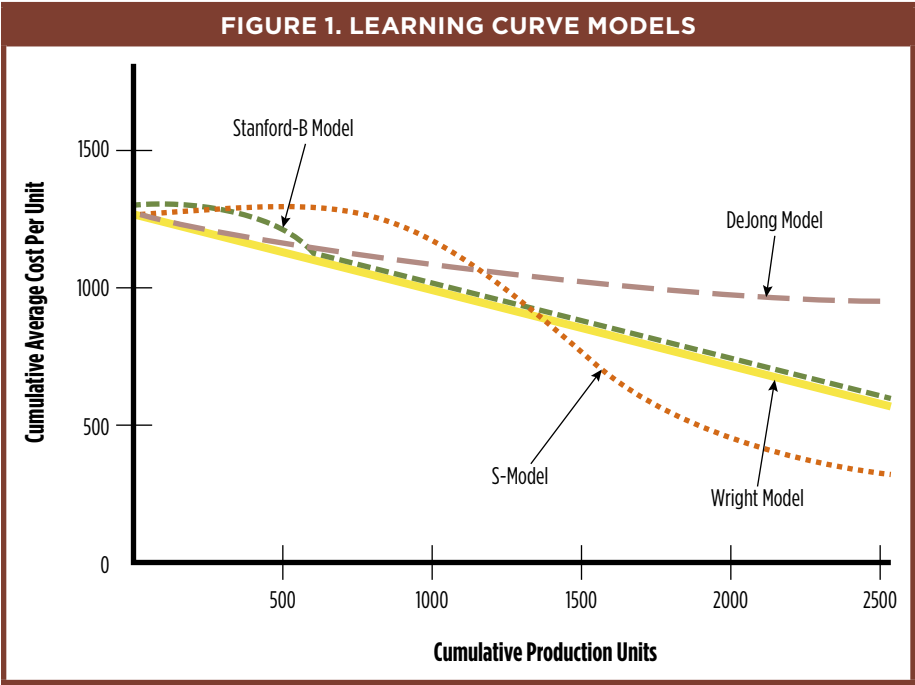
x = cumulative unit number

$b = \log R / \log 2$ = learning index

M = incompressibility factor (a constant)

B = equivalent experience units (a constant)

Figure 1 contains a graphical comparison of these three models. These models have specific, easily identifiable parameters that are more conducive for cost estimators to put to practical use. The goal is to make the estimator’s calculations more reliable and avoid a series of equations that decision makers must interpret.



Note. Adapted from Badiru, 1992.

Hypotheses Development

Wright's Learning Curve

The status quo for the learning curve models is Wright's Learning Curve (WLC) model, which takes the form $T_x = T_1 x^{-b}$. The two parameters that must be determined to perform an estimate are T_1 and b . In common cost estimating practices, b and T_1 are determined through a linear regression on a plot of the natural log of cumulative unit number $[\ln(x)]$ against the natural log of the actual reported costs $[\ln(y)]$. This regression will determine whether the cumulative average or unit learning curve theory should be applied to the data. The regression providing the most accurate fit according to the R^2 value will determine whether unit theory or cumulative average theory will be used for the remainder of the study. Once a theory is selected, the corresponding regression equation will be used to determine the parameters of the model. R^2 is a simple goodness-of-fit measure that represents the amount of variance between the independent and dependent variables expressed as a percentage. In other words, it represents the amount of variability that can be explained by the model (McClave, Benson, & Sincich, 2011). From the linear regression, b is simply the slope of the line and T_1 is derived by taking the natural log of the y-intercept. Once these two parameters are determined for Wright's model, they remain constant for the other three models used in this analysis.

Stanford-B Model

The first model selected for comparison was the Stanford-B model. The Stanford-B model is a relatively older application of the learning curve using the equation $T_i = T_1 (x + B)^{-b}$. The point of interest where this model differs from Wright's is the equivalent experience unit constant represented by the constant B . The B constant falls between 0 and 10 and represents the equivalent units of previous experience at the start of the production process. If more than 10 units have been produced, then the constant remains at 10. This parameter accounts for how many times the process has already been completed and adjusts the learning curve based on that number. The Stanford-B model is only a slight derivation from Wright's traditional learning curve model, and when B is equal to the first unit produced, then the models are identical (Badiru et al., 2013). Properly applying previous experience into the model is the key to using this equation, and for this study B is represented by the number of previous units produced. This can be in the form of prototypes, test aircraft, or any other relevant production unit that was not part of the F-15 A/B production lines. Twenty test units were produced beginning in 1970, which will be counted for prior experience, and therefore the factor B will be 10. This prior experience unit constant

of 10 will remain consistent when used in the S-Curve model described in the following section. With B determined, the data are incorporated into the model to estimate the total lot costs for the 15 remaining F-15 C/D and E lots. The residuals from these estimates, when compared to the actual lot costs, are then compared to each of the other three models to determine if one is a better fit than the others.

DeJong's Model

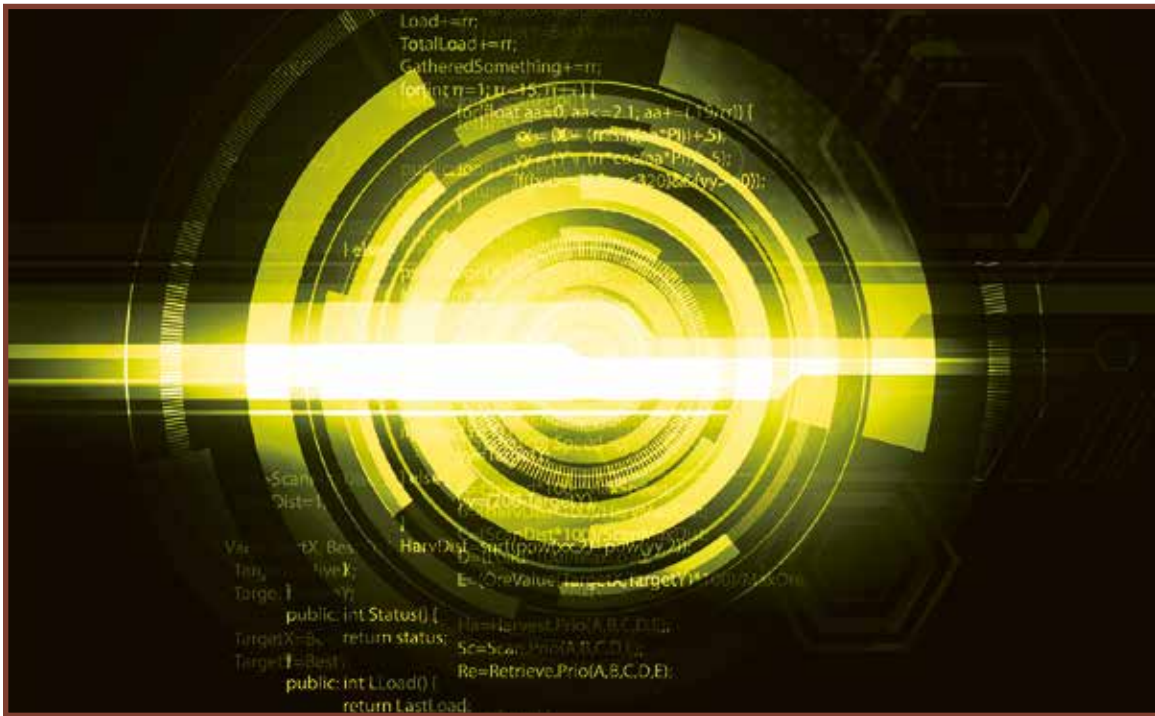
The second model used for comparison was the DeJong Learning Formula. DeJong's model is essentially a simple power function, similar to Wright's model, which accounts for the percentage of the task that requires mechanical activity to the amount that is touch labor. The effects of learning are typically only seen in touch, or human, labor because oftentimes, very few improvements in machine efficiency are observed over time. The basic form of this learning curve is $T_i = T_1 + Mx^{-b}$. Unlike previous models, DeJong's model incorporates the incompressibility factor (M); however, there is no equivalent experience constant. The incompressibility factor, M , is a constant between 0 and 1 where 0 represents a fully manual process and 1 represents a machine-dominated process (Badiru et al., 2013). Aircraft production falls somewhere between 0 and 1, but there is no precedent set for application to aircraft production. A U.S. Bureau of Labor Statistics report from June 1993 gives the following description of the industry: "[A]lthough the industry assembles a high-tech product, its assembly process is fairly labor-intensive, with relatively little reliance on high-tech production techniques" (Kronemer & Henneberger, 1993). This report indicates that the highly specialized process of aircraft production, similar to that of high-end performance automobiles, supports a proper application of M closer to 0 than 1. Where exactly that number falls is undefined and leads to some subjectivity. To avoid any biases that may skew the results and apply robustness to the analysis, the application of the constant will start at 0.0 and move to 0.2 in increments of 0.05, resulting in five sets of analyses. This range of incompressibility factors will remain consistent in the application of the S-Curve model as well.

S-Curve Model

The third and final model used for comparison in this study is the S-Curve model, which was developed by Towill and Cherrington in 1994. The S-Curve model is a combination of the Stanford-B model and DeJong's model. As mentioned earlier, this model is based on the assumption of gradual build-up early on in the production process (a period of steady learning), and then a flattened portion at the top of the S-Curve called the slope of diminishing returns, which is often attributed to forgetting. The basic

S-Curve model, $T_i = T_1 + M(x + B)^{-b}$, uses the same previous experience unit constant, B , and incompressibility factor, M , as the Stanford-B and DeJong models, respectively. Three of the four variables on the right side of the equation (T_i , b , M and B) must be known to make an assumption about the fourth (Badiru et al., 2013). In this study, we will use the same known T_i , b , and B used in the prior equations to make an educated assumption about M as described in the DeJong model discussed earlier. The S-Curve model is a very strong representation of how forgetting will affect the rate of learning and is a sound model to use in testing the theory.

Towill and Cherrington (1994) identify three primary sources for estimating error, the first being errors due to inevitable fluctuations in performance that occur naturally. Estimators have little if any control over this source. The second is psychological, physiological, or environmental causes that affect deterministic errors. These can be accounted for by estimators, but again this lies largely outside of their control. The final source for prediction error is modelling error, meaning that the form of the model used may be inappropriate and therefore not fit the trend line of the data. This research will address the third issue and attempt to determine the most appropriate model form that fits defense aircraft over a production life.



The premise for this study is that at least one of the alternative learning curve models is a more accurate predictor of actual production costs than traditional learning models. This theory is founded on the belief that forgetting occurs in airframe production, and models that do not assume a constant rate of learning will provide a more accurate estimate. The research hypothesis for this theory is that there is a significant difference between the Mean Average Percent Error (MAPE) of the predicted lot costs between the four models. MAPE is a measure of variation that takes the average of the absolute values from the error of each prediction. The absolute value is taken to avoid any cancelling out of positive and negative error values. The smaller the MAPE, the more accurate and reliable the estimates.

Addressing the issue identified by Towill and Cherrington (1994) led to the necessity for this line of research. This study will compare three modern learning curve models (Stanford-B, DeJong, and S-Curve) to Wright's learning curve and attempt to determine if one is more accurate than the others. The previous discussion leads to the following hypotheses:

H1: One or more of the four models compared will have a MAPE significantly different from the others.

H2: One or more of the modern learning curve models will be significantly more accurate than Wright's learning model in predicting aircraft costs.

H3: The S-Curve model will have the lowest MAPE and prove to be the most accurate predictor of aircraft costs over time.

The null hypothesis (H_o) for the first hypothesis in this study is that $\mu_1 = \mu_2 = \mu_3 = \mu_4$, meaning all of the MAPEs are the same, as contrasted against the alternative hypothesis (H_a) that at least one of the models has a mean that is different. If the null hypothesis can be rejected and the evidence supports a significant difference, then it will be necessary to test each of the new learning models against the conventional model. The second null hypothesis mathematically states that $\mu_i = \mu_1$ where $i = 2, 3, 4$ to be tested against the $H_a: \mu_i > \mu_1$. These individual hypotheses test whether each of the modern learning curve models has a MAPE significantly lower than the conventional model. One final test will be to investigate the third hypothesis and determine which of these models that has displayed significantly smaller mean errors from the conventional model is the best predictor. The third null hypothesis states that $\mu_i = \mu_j$, where i and j are both significantly

lower than μ_1 , to be tested against the $H_a: \mu_1 > \mu_1$. That analysis will provide an answer to the initial inquiry of this research of determining if an alternative *best fit* model is more accurate than Wright's model.

Methods

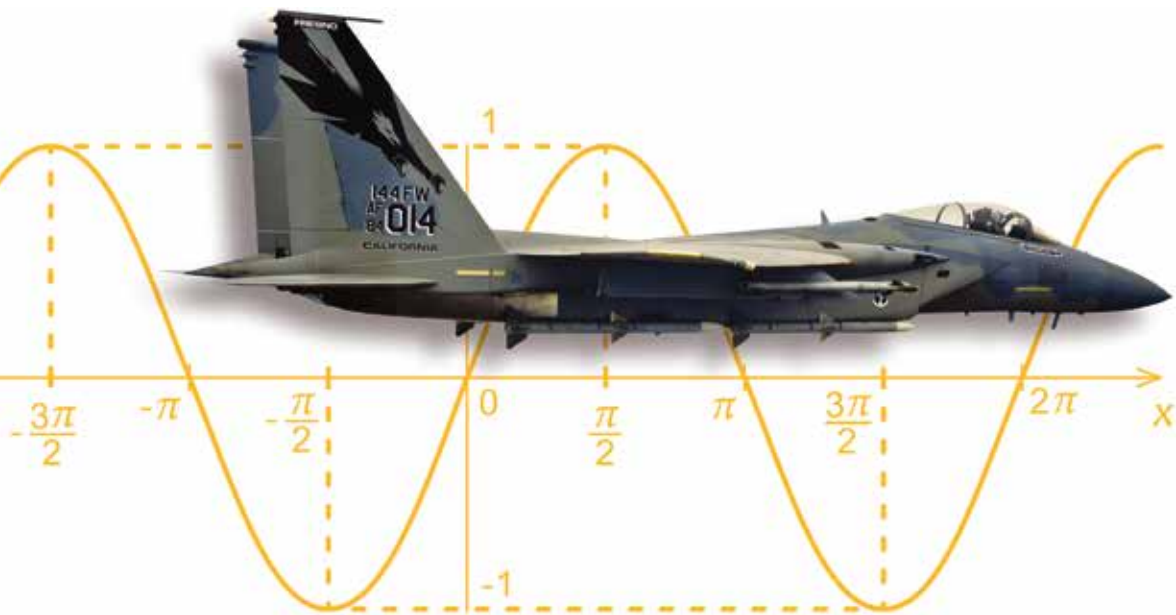
The initial task is to determine which of the models should be used in comparison to conventional learning curves, and how to improve upon conventional learning curve application. Several learning and forgetting curve models were identified for application in this study, but the three models selected are based on a literature review and subject matter expert (SME) opinion from cost analysts. These SMEs confirmed the Stanford-B model, DeJong's Learning Formula, and the S-Curve model are applicable to cost estimation and should be examined in the DoD environment. Additionally, they agreed the conventional Wright's model lacks the application of key factors such as prior experience and incompressibility that affect learning. Accounting for these previously unrecognized factors may reduce the amount of estimating error for airframe costs. In the DoD environment, an error reduction of a modest 5 percent could greatly enhance our ability to understand the cost overruns over the life of a program. The three models discussed in this article account for one or more forgetting factors, which can be easily assessed by cost estimators and quickly incorporated into current estimation techniques. The applicability and ease of use are other primary factors behind the selection of the models reviewed in this study. Providing a model that takes hours or days of secondary analysis and data collection is of little practical value to estimators, even if it proves more accurate. The following section explains how those models will be applied to the data in this study, which methods will be used to compare them, and how the data are analyzed in this research.

In the DoD environment, an error reduction of a modest 5 percent could greatly enhance our ability to understand the cost overruns over the life of a program.

Data

Airframe costs were chosen for this analysis for a number of reasons. First, using airframe costs allows for the assumption of homogeneity over multiple model types. One can safely assume that the F-15 A/B, C/D, and E all have similar if not identical airframes, making it easier to compare the costs and examine the learning process. Also, in Foreign Military Sales (FMS) to the allies of the United States, the airframe of the aircraft typically does not change despite changes to avionics or electronics systems. Also, Badiru et al. (2013) state, “as rapid emergence of new technology necessitates that airframe designs and manufacturing processes be upgraded frequently... the opportunity for forgetting clearly increases.” Therefore, the application of airframe costs to this study will provide results consistent with that theory.

After some initial investigation, fighter aircraft became the primary platform type for this analysis for a multitude of reasons, the first reason being that several years of production data exist and hundreds of units were produced for these aircraft. Note that over 1,150 aircraft were produced in a 20-year span for the F-15 alone. Bailey (1989) stated that forgetting is a function of both the amount of learning and the passage of time. This makes the analysis of aircraft production cycles spanning over several years a prime candidate to exhibit the declining performance rate attributed to forgetting. The second reason is that the Air Force has several models of fighters (F-15



A-E and F-18 A-F, to name a few) in its inventory—all of which are variants of the same basic airframe, making the assumption for comparison of airframe costs from model to model possible. The final reason for choosing fighters was the ability to work face to face with cost estimators from the program offices located at Wright-Patterson Air Force Base, Ohio. Their assistance as SMEs would prove invaluable in verifying our assumptions and verifying the parameter estimates for our models.

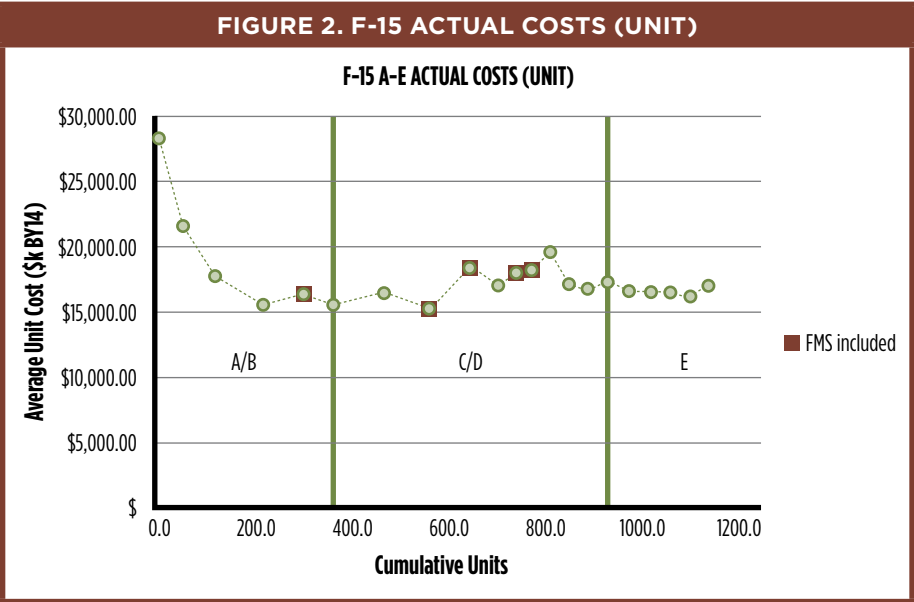
The initial pool of aircraft data collected for analysis consisted of five fighters: the Air Force F-15, F-16, and F-22; the Navy F/A-18; and the joint (Air Force, Navy, and Marines) F-35. We eliminated the F-35 from analysis due to too few data points available. The F-22 was eliminated from consideration because it had two primary contractors: Lockheed Martin Aeronautics and Boeing Defense, Space, and Security. These two contractors both contributed components to the airframe production, making it difficult to measure and assess the effects of learning since production processes were not consistent between the two companies. For this reason, it does not provide a suitable comparison to other aircraft being tested. The F-16 was a prime candidate for analysis given the long production life and model upgrade, but relevant airframe data were incomplete or missing altogether in some cases. The F/A-18 had sufficient available data, but the program switched primary contractors, making it difficult to homogenously compare the costs over that transition. This left the F-15 as the primary platform for analysis based on production history and availability of relevant airframe costs.

F-15 airframe costs were acquired from two databases. The F-15 A-D airframe lot averages were acquired from the *Cost Estimating System, Aircraft Cost Handbook*, published in 1987 by the Delta Research Corporation. This handbook includes all 19 lot purchases from 1970–1985 and details the quantity produced as well as the total airframe costs (minus administrative costs). These data were presented in Base Year 1987 dollars (BY\$87), meaning that the values for each year are set at a fixed price as if all of the funds were expended in 1987 (DoD, 2007). Summarized, this statement means that each of the values was initially represented at its equivalent purchasing power in the year 1987.

The F-15E data were taken directly from the Joint Cost Analysis Research Database (JCARD) system. These data were much more detailed and included five of the six lot purchases, with Lot 1 data missing. The system had data broken out into each cost element (including airframe) and the total quantity produced. The JCARD data were in Then Year dollars (TY\$), which are BY\$ inflated/deflated to represent the purchasing power of the funds if

they were expended in that given year (DoD, 2007). Both the F-15 A-D BY\$87 values and the F-15E TY\$ values are standardized in this research to a Base Year 2014 (BY\$14) value using the 2014 Office of the Secretary of Defense (OSD) Inflation Tables. The OSD Inflation Tables are published every year, and this research was begun in 2014 so those tables have been used to avoid crossing over to and from inflation tables. This step ensures that all dollar amounts are compared on a level plane and also represent a dollar value that is relevant to today’s economy.

The unit theory data of the entire F-15 A-E data set are shown in Figure 2. The data indicate that the later stages of the production cycle show possible signs of forgetting. The average unit cost is actually increasing towards the end of production rather than decreasing as would be predicted by Wright’s learning theory. The F-15 data appear to show significant signs of declining performance over the program’s life cycle in the sharp flattening trend in the data. After the production of around 600 units, the effects of learning nearly come to a complete stop and, in some cases, the costs actually increase over time.



Note. Average Unit Cost reflects actual cost per unit to the government for airframe only.

The goal of this study is to identify a model, or models, which more accurately predict the decline in performance over time and provide more accurate estimates for airframe costs than Wright’s contemporary model.

For this research, the F-15 A/B lots will be treated as historical data, and each of the models will be used to estimate the costs for the C/D and E lots based on that data. This scenario allows for the simulation of a *real-world* cost estimating scenario rather than a controlled study where the data are treated in a way that is beneficial to the researcher.

Analysis Methods

Once the data are standardized to BY\$14 averages, the estimates from each of the models will be recorded using one of the four models described. There will also be data collected for cumulative units and lot number. An error term is calculated, which is the difference between the actual and predicted (Unit or Cumulative Average Theory) values. Absolute error (Abs Error) is simply the absolute value of the error, and absolute percent error (Abs PE) is the absolute error divided by the actual cost.

Once the data are coded, the next step is to perform the analysis and test the hypotheses. For the overall research hypothesis $\mu_1 = \mu_2 = \mu_3 = \mu_4$, the set of percent errors will be compared using an analysis of variance (ANOVA) method, as well as the Kruskal-Wallis (KW) test. These tests produce an *F*-statistic falling within a Chi-distribution and a resultant *p*-value that will either support or not support the null hypothesis based on the given confidence level. The null hypothesis is that all of the sample means are the same while the alternative hypothesis is that at least one of the sample means is different. The KW test is used to determine whether multiple samples arise from the same distribution and have the same parameters (Kruskal & Wallis, 1952). An *F*-test from the initial ANOVA and KW test, both performed in SPSS Statistics software, will provide insight into the first hypothesis. If the *F*-statistic is significant, then at least one of the sample means is different.

To test the second hypothesis (that at least one of the models is more accurate), this research will use Dunnett's test performed in SPSS. Dunnett's test is used to compare multiple sample means to one value held as the control (Everitt & Skrondal, 2010). Wright's learning curve model, the status quo, will be used as the control for this study, and the significance will be used to test if any of the other models' MAPE values are less than (<) the control. If the assumption for equal variance is not met, Dunnett's T3 test will be used for comparing the sample means. The T3 is similar to Dunnett's test described earlier, but it uses each sample as a control individually to compare against the other values.

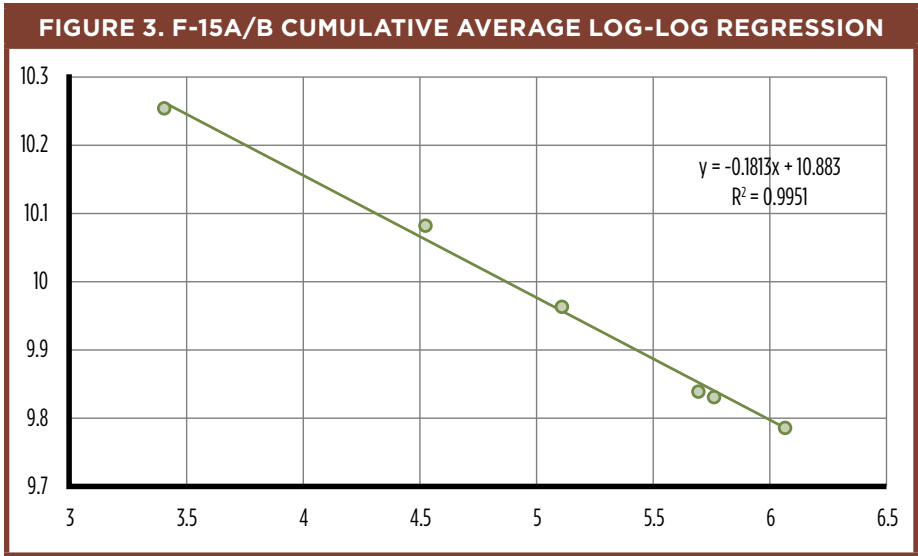
The final test will be to analyze which model is most accurate given significant results from previous tests. This analysis will be conducted through a simple paired difference t test—again performed in SPSS. A paired difference experiment uses a probability distribution when comparing two sample means and produces a t statistic that falls within a student t distribution that can either reject or fail to reject the null hypothesis, depending on the desired confidence level (McClave et al., 2011). If the assumption for equal variances is not met and the T3 test is used, information regarding which models are significantly different will be found in the T3 test, and there will be no need for paired t tests.

For this analysis, an F -statistic (or t -statistic) with a resulting p value < 0.05 will support rejection of the null hypotheses and support the alternative hypothesis that the mean values between the models are different. A p value, or observed significance level (McClave et al., 2011), is defined as: “the probability (assuming H_0 is true) of observing a value of the test statistic that is at least as contradictory to the null hypothesis, and supportive of the alternative hypothesis, as the actual one computed from the sample data.”

In other words, the p value is the chance of having an actual result that is contradictory to the sample result. By rejecting the null hypothesis, the data are essentially demonstrating a 95 percent chance that the means of the two populations are different.

F-15 C-E Analysis

Unit Theory and Cumulative Average Theory. The first step of the analysis was to identify which learning theory was most appropriate for the given data. For the F-15 data using an M value of 0.20, a log-log regression was run against the A/B model data, using both the unit theory and cumulative average theory to predict the learning parameters for the C/D and E models used in the analysis. Figure 3 shows the regression using the cumulative average theory, which produced an R^2 value of 0.9951. The cumulative average R^2 value for the A/B model was slightly higher than the 0.9735 value produced using the unit theory data. This indicates that the cumulative average theory should be used for estimating the C-E model costs, and the lot-plot point assumption holds for the data.



These results also provide the basic parameters for all four learning models used in the study. The learning rate factor, b , is the slope of the linear regression line, which in this case is -0.1813 . This value indicates a learning curve slope of 88.19 percent ($LCS=2^b$). Figure 3 also provides information about the T_1 value that is used in the analysis. The intercept of the linear regression equation is the natural log of the theoretical unit 1, T_1 , value. By raising the mathematical constant e to the value of the intercept (10.883), one can determine the average cost of the theoretical first unit; in this case, that value is \$53,263.

Assumption Parameters. The next step was to populate the data tables so that the comparative analysis could be performed. Table 1 shows the Absolute Percent Error (APE) values for all 15 lots calculated using each of the four learning models with an incompressibility factor of 0.1. As the table shows, Wright’s Curve and the Stanford-B models initially have the lowest MAPE of the four models, but analysis must be conducted to determine whether the data reflect a significant difference. That analysis can then be applied to a range of incompressibility factors to determine how sensitive the results are to a change in that factor.

TABLE 1. F-15 APE VALUES FOR EACH MODEL				
M = 0.1				
Lot	WLC	Stanford-B	DeJong	S-Curve
7	0.0549032	0.0509017	0.2716447	0.2680433
8	0.0927225	0.0892703	0.3285742	0.3254672
9	0.1085792	0.1085792	0.0904993	0.0882712
10	0.0530433	0.0554482	0.1634820	0.1613176
11	0.1172022	0.1193309	0.0873964	0.0854805
12	0.1272667	0.2192897	0.0771023	0.0752816
13	0.1958247	0.1975958	0.0049876	0.0065815
14	0.0816980	0.0836323	0.1387508	0.1370100
15	0.0764948	0.0783588	0.1476580	0.1459804
16	0.1119286	0.1136465	0.1059919	0.1044458
17	0.0813009	0.0829968	0.1468597	0.1453335
18	0.0823053	0.0839250	0.1482298	0.1467721
19	0.0880680	0.0896143	0.1433682	0.1419766
20	0.0824747	0.0839757	0.1525089	0.1511580
21	0.1269814	0.1283646	0.0984203	0.0971754
AVG	0.0987196	0.0996620	0.1403659	0.1386863

Note. WLC = Wright's Learning Curve.

To analyze the samples, certain assumptions must be tested. The assumption of normality was not met, meaning that nonparametric tests must be used for comparing the means. Kurtosis is a measure of the *peakedness* of the distribution, and the high kurtosis values from the data set imply the data are non-normal and result in a sharply peaked distribution. All of the samples also have a skewness greater than 1, so normality cannot be assumed. The KW test must be used to determine whether the sample distributions are significantly different and if at least one sample has a median different from the others.

The tests for equal variances were not uniform through the range of incompressibility factors, and therefore certain values were tested using the more conservative Dunnett T3 test (if variances are unequal) rather than the Dunnett test (if variances are assumed equal), which only uses one control.

Regardless of which means comparison was used, the results indicate which models are significantly different from the WLC status quo. The results of all five tests are summarized in Table 2.

TABLE 2. MAPE COMPARISON RESULTS					
	M = 0.0	M = 0.05	M = 0.10	M = 0.15	M = 0.20
WLC	N/A	N/A	N/A	N/A	N/A
Stanford-B	X	X	X	X	X
DeJong	X	-	X	+	+
S-Curve	X	-	X	+	+

Note. MAPE = Mean Average Percent Error; WLC = Wright's Learning Curve
X indicates model is not significantly different from WLC
(+) indicates model is statistically less accurate than WLC (Higher MAPE)
(-) indicates model is statistically more accurate than WLC (Lower MAPE)

When the factor was held at 0.0 or 0.1, there was no statistical difference between the models, and these results reject all of the hypotheses. On the contrary, when the factor is held at 0.05, the DeJong and S-Curve models are more accurate, and these findings support all three of the hypotheses. When the incompressibility factor rises to 0.15 and 0.20, Wright's model holds as the most accurate. Results for all five means' comparison tests are displayed in the Appendix. In all cases, no statistical difference was shown between Wright's model and the Stanford-B model, and the same was true when comparing the S-Curve model and DeJong's model. This illustrates that in high production volumes, such as the 1,100-plus F-15s produced, incompressibility becomes much more significant than the prior experience units factor.

Results

The results of this research are inconclusive regarding an answer to the overarching research question of whether a more accurate learning curve model is available for DoD use than Wright's original formulation. However, the results do provide some insight into the effects of learning and where to go from here. The findings also emphasize the importance of incompressibility (*M*) in the learning process. Slight changes in the assumed incompressibility of the process led to drastically different results as to which model was most accurate.

The first hypothesis from this research was that at least one of the models would have a MAPE value statistically different from the others. This was not the case when the incompressibility factor was assumed to be 0.0 or 0.1, but the hypothesis holds for values of 0.05, 0.15, and 0.20. These results indicate that, although not uniformly, there does appear to be evidence that at least two of the models display a statistical difference. This result is important because it sets up the framework to be able to test the other hypotheses in the study.

The second hypothesis was that at least one model would have a MAPE value statistically lower than Wright's model. This hypothesis held only when the incompressibility factor was assumed to be 0.05; in all of the other cases, no statistical difference was calculated at 0.1, and the models were actually less accurate than Wright's model when $M = 0.15$ and 0.20 . This finding indicates that as the process becomes more automated, Wright's curve actually performs better. These results do not fully support the second hypothesis, but do illustrate potential for learning curve improvement if an actual, universal incompressibility factor is found to be somewhere between 0.0 and 0.1. Post hoc analysis found that the S-Curve and DeJong models switch from being statistically more accurate to having no significant difference in MAPE value somewhere between 0.05 and 0.06. The follow-on research section will provide potential impacts of a statistically supported incompressibility factor and how that factor could potentially support the findings from these results.

The findings of this research lead to two additional theoretical questions: why were the results so sensitive to the incompressibility factor, and what conclusions can be drawn about the application of modern learning models in DoD acquisition?

The final part of this analysis was to test which model was the most accurate between the four. The third hypothesis from this research was that the S-Curve model would be the most accurate because it accounts for the slow decline in performance over time due to forgetting. As with the second hypothesis, this hypothesis is only partially supported when the incompressibility factor is assumed to be 0.05 and rejected by the other results. At 0.05, both the DeJong and S-Curve models are more accurate than Wright's

model; however, neither the DeJong nor S-Curve proved to be more accurate than the other. These results lead to inconclusive outcomes about which model is best, but again point to the importance of the incompressibility factor when determining best model fit.

The findings of this research lead to two additional theoretical questions: why were the results so sensitive to the incompressibility factor, and what conclusions can be drawn about the application of modern learning models in DoD acquisition? While the second question will be addressed at the end of this section, the first question may be due to the data itself. The incompressibility factor essentially represents the amount of potential learning that is lost for each unit due to automated production processes. If an incompressibility factor is 0.3, then only 70 percent of the potential learning can be achieved. When compounded over several lots and units (over 1,100 units for the F-15 A-E), a small shift in that percentage can result in a massive change in the cost of the units at the end of the production process.

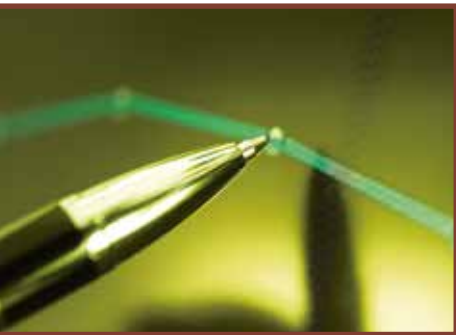
This sensitivity affirms the need for additional research into incompressibility factors within the DoD and defense contractors in general. As mentioned earlier, the production of an aircraft is not unlike the production of a high-end sports car. The level of precision and craftsmanship required eliminates the use for certain automated processes that may be present in an assembly line at Ford or Toyota. Given this dynamic, assuming the real incompressibility factor is somewhere between 0.0 and 0.1 is not implausible. Follow-up investigation, involving inquiries to top practitioners and SMEs in the learning curve field, supports the belief that the percentage of automation is very, very small in an aircraft production environment. Additionally, different defense contractors may use various production processes that result in different incompressibility factors and thus increase the sensitivity of the costs to those factors. This is yet another reason for future incompressibility research that will be described later in this section.

These results also indicate that learning is affected much more by incompressibility than prior experience units. The prior experience units parameter (B) was the differentiating parameter between the WLC and Stanford-B model, as well as the difference between DeJong's learning formula and the S-Curve model. One explanation for this result may be the large number of units produced for the F-15. When examining over 1,100 units, a change to a mere 10 of the units will have a very limited impact on the outcome. However, if the same prior experience units' factor was applied to a smaller production line such as the 21 original units of the B-2 bomber, the difference may become very significant. In all five cases, there was no

statistical difference between the model and its close relative, meaning that the maximum change in B of 10 had no impact on the long-term estimates of the models. Therefore, it is safe to assume that simply adding a prior experience units' factor alone provides no value to the estimate if the production number is high, but the interaction between prior units and incompressibility could be very significant.

Significance of Research

The results discussed in the previous section indicate that there is potential for a more accurate model in predicting the effects of learning within DoD acquisition. This study was unique in two primary areas. First, it investigated defense aircraft costs where past studies had primarily investigated commercial aircraft or components; and second, due to its nature, DoD cost estimating examines costs from an external perspective rather than internal. Therefore, the availability and accuracy of data may lead to more assumptions than prior studies.



Despite these intricacies, a few major conclusions can be drawn from the results. The first is that there is potential with two of the alternative learning curve models to increase estimate accuracy using learning curves by up to 5 percent over the entire production cycle based on the results for an incompressibility factor of 0.05. Post hoc analysis indicated that the largest difference between the Wright and S-Curve models—just over 5.2 percent—was seen at 0.04. While this percentage may seem small, for the more than \$20 billion production cycle of the F-15 A-E airframes, this percentage could

reduce error in the estimation process by as much as \$1 billion simply by changing the estimating tool. This research does not go so far as to say current cost estimating methodology is wrong; cost estimates are just that—estimates. This research suggests and hopes to provide the foundation for ways to improve current learning curve methodology. Determining which model is most appropriate is an area that requires more analysis. Thus far, the S-Curve and DeJong models appear to be worthy candidates. Further analysis incorporating incompressibility could reveal more information related to the application of the S-Curve and DeJong models, and consequently, the theory of forgetting within DoD methodology.

While the findings of this study do not support all of the hypotheses of this research or indicate which model is the best predictor of future costs, they do open up a dialogue for future change in DoD acquisition methodology.

These results stress the importance of incompressibility in learning and the potential for improvement based on that significance. Data collected during the initial production run of a weapon system could be used as a baseline to establish an incompressibility factor that is specifically tailored to that weapon system and production environment. Future research into incompressibility in aircraft production and comparative research into additional airframes as well as any of the dozens of other learning models available may help provide decision makers with additional information, and hopefully increase the accuracy of cost estimates as a whole. Additionally, the use of an incompressibility factor should not be limited to aircraft, as every weapon system production process utilizes some form of automated manufacturing. One of the primary contributions of this research is to highlight the importance of incompressibility and the relationship it has with the production process. Recognizing that each weapon system may have a unique incompressibility factor and incorporating this into estimation techniques should greatly improve cost estimates across weapon systems.

Assumptions and Limitations

As always, there are limitations to this research and the methods used to test the hypotheses. One limitation to this study was the amount of data available for analysis. While some of the results from the analysis appear to be inconclusive, the data presented in this analysis are only a small fraction of all aircraft programs, and an even smaller portion of DoD programs as a whole. The Air Force Life Cycle Management Center/Financial Management Mission Execution Directorate (AFLCMC/FZ) has access only to programs under their control, and only data from those programs that reported on learning curves. These factors will limit the number of aircraft available for future analysis. A larger data set would have been preferred, but in this case the sample was limited to the data available. Follow-on analysis of incompressibility and additional Air Force and DoD programs are necessary before generalization of the findings can be made.

Another limitation is the accuracy of the data reported as actual costs. The accuracy, or lack thereof, in updating actual values for estimates has long been an issue in DoD, and has just recently been brought to light in an effort to clean up data repositories. However, the fact that many of the programs are under AFLCMC/FZ local control and span multiple decades should help to mitigate some of the uncertainty of the results.

One other potential limitation was the use of the lot plot point with the cumulative average theory. Lot data are often used in DoD cost estimates due to the nature of contractor reports, but that type of analysis has not been applied to the additional models used in this analysis. However, the

methods used were backed up by the AFCAH as well as other studies into learning curves. This methodology, in addition to the fact that lot data are widely used throughout the DoD, should reduce the effect the lot plot point assumption has on the results while simultaneously making them more generalizable to individual unit data.

Recommendations for Future Research

This research answered several questions about the effects of learning in DoD, but there are still more questions that need to be addressed. Further, it sought to determine whether any alternative learning models are more accurate than Wright's model, which is commonly used throughout defense acquisition programs today. This study took steps toward accomplishing that goal and found that the S-Curve and DeJong models may be more accurate if the incompressibility factor for aircraft production is found to be between 0.0 and 0.5. However, the evidence is inconclusive as to which model is the most accurate, and results are extremely dependent on the assumptions made. Additional research into incompressibility factors would prove valuable to this learning curve analysis and paramount to any additional research using these models. As mentioned earlier, one of the major assumptions in this study was in the use of an incompressibility range from 0.0 to 0.2. Future research into what incompressibility factor should be used for aircraft production would provide insight into which models may be more appropriate, and also provide further insight into the validity of these results. Also, analysis into how incompressibility factors change between different defense contractors or how different platform types affect the production process could provide even more accuracy in future research. Clarifying these uncertainties will help produce more accurate and useful cost estimates using the models described in this article.

Future research should also look to broaden the scope of the programs used in this analysis. This research focused on fighter aircraft, and the initial pool of six was trimmed down to one aircraft. Follow-on studies should attempt to incorporate the findings in additional platforms such as bombers, cargo/tanker, and unmanned aircraft. Also, the use of additional models that do not rely on an incompressibility factor may provide more robust results. Results from the analysis of the F-15 should not necessarily be generalized to all aircraft as a whole. Further analysis may shed light on which models perform best on which aircraft or whether there is a single model that can be generalized to all platforms.

Summary

When this research began, the goal was to find out whether a more accurate learning curve model for use in DoD exists. The AFLCMC cost staff supported the effort to find a way to improve current learning curve methodology in defense acquisition. Through the efforts of this research and the findings entailed within, there is evidence to support the hypothesis that at least one of the models may be more accurate than Wright's original model. This research found that both the DeJong and S-Curve models are statistically more accurate than the status quo when the incompressibility factor is somewhere between 0.0 and 0.5. However, if the factor is assumed to be .01 or higher, then Wright's model is the most accurate and the additional models do not improve on the current methodology. The results as to which model is the most accurate are inconclusive and do not support nor disprove the hypothesis that the S-Curve model is the most accurate of the four. At a minimum, this research provides the foundation for further research into additional types of aircraft as well as an applicable incompressibility factor that may indicate which model is the most accurate. Only then can the alternative models be considered for DoD methodology.

One premise behind this research is that the current DoD learning curve methodology using Wright's 75-plus-year-old model should not be accepted as the status quo for the sake of simplicity or nostalgia.

One premise behind this research is that the current DoD learning curve methodology using Wright's 75-plus-year-old model should not be accepted as the status quo for the sake of simplicity or nostalgia. If a more accurate learning model exists that can be applied to cost estimating within the DoD, it should be investigated and considered. This research illustrates the point that additional models are available. Some are more accurate in certain cases, and would undoubtedly provide the foundation for future research in defense acquisition, which can hopefully increase the accuracy and reliability of cost estimates and result in a more efficient use of government funding.

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Appendix

Dunnett T3 Test Results

DUNNETT T3 TEST ($M = 0.0$)						
(I) Model	(J) Model	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00	2.00	-.00094	.01299	1.000	-.0375	.0356
	3.00	.00000	.01288	1.000	-.0363	.0363
	4.00	-.00111	.01299	1.000	-.0377	.0355
2.00	1.00	.00094	.01299	1.000	-.0356	.0375
	3.00	.00094	.01299	1.000	-.0356	.0375
	4.00	-.00017	.01309	1.000	-.0371	.0367
3.00	1.00	.00000	.01288	1.000	-.0363	.0363
	2.00	-.00094	.01299	1.000	-.0375	.0356
	4.00	-.00111	.01299	1.000	-.0377	.0355
4.00	1.00	.00111	.01299	1.000	-.0355	.0377
	2.00	.00017	.01309	1.000	-.0367	.0371
	3.00	.00111	.01299	1.000	-.0355	.0377

Note. Dunnett t tests treat one group as a control and compare all other groups against it.

DUNNETT T3 TEST ($M = 0.05$)						
(I) Model	(J) Model	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
2.00	1.00	.00094	.01784	1.000	-.0421	.0440
3.00	1.00	-.04616*	.01784	.033	-.0892	-.0031
4.00	1.00	-.04670*	.01784	.030	-.0898	-.0036

* The mean difference is significant at the 0.05 level.

DUNNETT T3 TEST (M = 0.1)						
(I) Model	(J) Model	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00	2.00	-.00094	.01299	1.000	-.0375	.0356
	3.00	-.04165	.02199	.343	-.1055	.0222
	4.00	-.03997	.02178	.376	-.1032	.0232
2.00	1.00	.00094	.01299	1.000	-.0356	.0375
	3.00	-.04070	.02204	.369	-.1047	.0233
	4.00	-.03902	.02184	.404	-.1024	.0243
3.00	1.00	.04165	.02199	.343	-.0222	.1055
	2.00	.04070	.02204	.369	-.0233	.1047
	4.00	.00168	.02814	1.000	-.0776	.0810
4.00	1.00	.03997	.02178	.376	-.0232	.1032
	2.00	.03902	.02184	.404	-.0243	.1024
	3.00	-.00168	.02814	1.000	-.0810	.0776

DUNNETT T3 TEST (M = 0.15)						
(I) Model	(J) Model	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00	2.00	-.00094	.01299	1.000	-.0375	.0356
	3.00	-.15035*	.02337	.000	-.2185	-.0822
	4.00	-.14856*	.02328	.000	-.2164	-.0807
2.00	1.00	.00094	.01299	1.000	-.0356	.0375
	3.00	-.14941*	.02343	.000	-.2176	-.0812
	4.00	-.14762*	.02333	.000	-.2156	-.0797
3.00	1.00	.15035*	.02337	.000	.0822	.2185
	2.00	.14941*	.02343	.000	.0812	.2176
	4.00	.00179	.03037	1.000	-.0838	.0874
4.00	1.00	.14856*	.02328	.000	.0807	.2164
	2.00	.14762*	.02333	.000	.0797	.2156
	3.00	-.00179	.03037	1.000	-.0874	.0838

* The mean difference is significant at the 0.05 level.

DUNNETT T3 TEST (M = 0.2)							
(I) Model	(J) Model	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval		
					Lower Bound	Upper Bound	
1.00	2.00	-.00094	.01299	1.000	-.0375	.0356	
	3.00	-.25972*	.02454	.000	-.3314	-.1880	
	4.00	-.25804*	.02445	.000	-.3295	-.1866	
2.00	1.00	.00094	.01299	1.000	-.0356	.0375	
	3.00	-.25877*	.02459	.000	-.3306	-.1870	
	4.00	-.25709*	.02451	.000	-.3286	-.1855	
3.00	1.00	.25972*	.02454	.000	.1880	.3314	
	2.00	.25877*	.02459	.000	.1870	.3306	
	4.00	.00168	.03216	1.000	-.0889	.0923	
4.00	1.00	.25804*	.02445	.000	.1866	.3295	
	2.00	.25709*	.02451	.000	.1855	.3286	
	3.00	-.00168	.03216	1.000	-.0923	.0889	

* The mean difference is significant at the 0.05 level.

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TECHNICAL Data Packages:

When Can They **Reduce Costs**
for the Department of Defense?

 *Nicholas J. Ross*



This article presents an economic model analyzing the impact of research and development (R & D) costs, production costs, and quantity requirements on the price of a Technical Development Package (TDP). It compares payoffs in a game involving a duopoly of defense firms and the government to analyze potential cost savings to the government by purchasing a TDP. It concludes that the price of a TDP depends primarily on rival firms' R&D as well as production costs. The government is most likely to achieve cost savings in the case where a rival firm has lower production costs, but would lose a competitive bid without a TDP. However, a TDP does not automatically lead to competition-based savings. The author then discusses the implications of relaxing key assumptions of the model.

Keywords: *national defense economics, competitive procurement, competition-based savings, data rights, technology transfer*



In the acquisition of many weapon systems, the Department of Defense (DoD) must decide whether to buy a Technical Data Package (TDP), which contains the information needed to produce them. The government faces a tradeoff: pay for a TDP and try to save money by competing production and sustainment, or decline to purchase a TDP and possibly pay much more for new systems, spares, and repairs. This article examines this tradeoff by comparing payoffs in a game of a duopoly of defense contractors. While it focuses on the role of TDPs, competition, and the procurement of systems, there are naturally other important uses of TDPs such as allowing the government to conduct better engineering and logistics analysis. The model suggests that the price of a TDP depends on the cost to replicate it via an independent research and development (R&D) effort, relative production costs between firms, and the quantity of systems procured. It further discusses implications of relaxing key assumptions of the model.

Background

Economists and policy analysts disagree about the role of competition in the procurement of defense systems. They can be grouped into two broad opposing groups. One group believes that setting up a competition between multiple prime contractors leads to lower costs for the government. The other group contends that using multiple prime contractors reflects political realities or industrial base concerns, and does not provide efficiency gains through competition.

In the first group, Lyon (2006) concludes in an analysis of missile production, “dual sourcing appears to produce procurement cost savings” (p. 248). Gansler, Lucyshyn, and Arendt (2009) argue that employing competition reduces costs by stressing that competition provides strong incentives for contractors to reduce costs while providing high-quality products. Kovacic and Smallwood (1994) stress the role of competition in promoting innovation by contractors, but recognize cost savings as a secondary benefit. Driessnack and King (2007) argue that the use of subcontractors by prime contractors has several benefits, including “decreasing costs by increasing the level of competition and innovation in the defense industry through increased outsourcing” (p. 64).

In their analysis of rising ship costs for the U.S. Navy over the last half century, Arena, Blickstein, Younossi, and Grammich (2006) argue a contrasting perspective: “The reality is that using multiple producers can make a program more politically palatable” (p. 46). They go on to state, “Although

competition might help reduce prices, there is also little evidence ... that current ‘allocation’ processes gain the benefits of competition” (p. 65). In a similar study comparing the production of the F/A-22 and the F/A-18 aircraft, Younossi, Stem, Lorell, and Lussier (2005) note that the “artificial distribution of work” among several major contractors helps explain in part the higher costs of the F/A-22 when compared to the F/A-18, which used a single prime contractor (p. xviii).

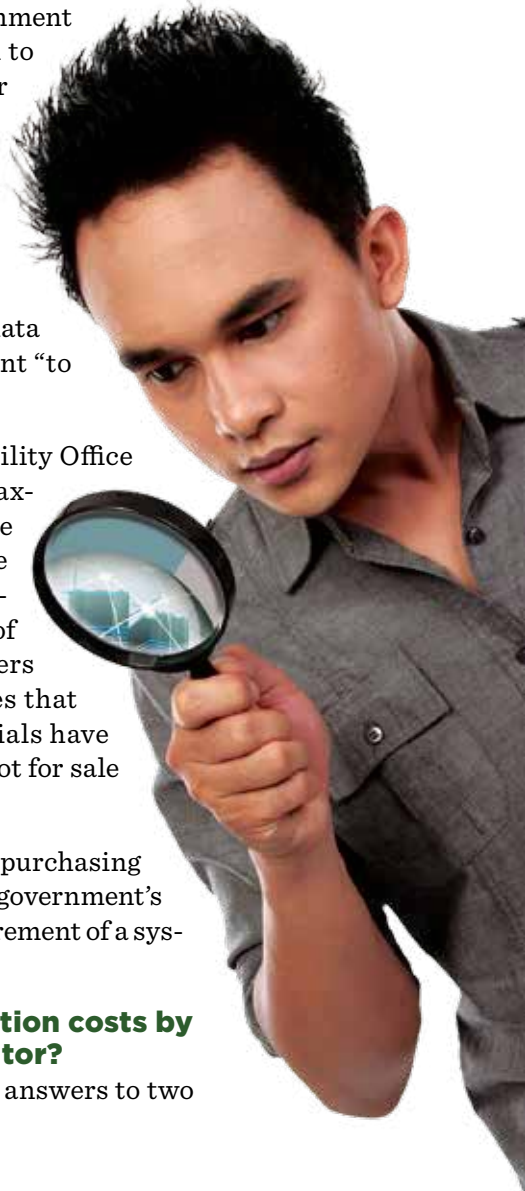
This debate is not merely academic: the U.S. Government has taken an active interest in using competition to reduce the costs of weapon procurements. An Under Secretary of Defense for Acquisition, Technology, and Logistics memorandum states, “competition is the most effective tool we have to control cost” (Kendall, 2015, p. 23). Guidelines produced by this office claim, “competition . . . is the most effective motivator for industry to reduce costs and improve performance” (DoD, 2014a, p. 1). It also suggests, “data deliverables and rights” are a necessary component “to realize the full benefits of competition” (p. 2).

On defense contracts, the Government Accountability Office (GAO, 2013) reports competition “can help save taxpayer money, conserve scarce resources, improve contractor performance, curb fraud, and promote accountability for results” (p. 1). In a study on competition in contracting, GAO has observed, “lack of access to technical data as one of the main barriers to competition” (GAO, 2010). However, GAO notes that when several program offices or contracting officials have attempted to obtain technical data, it “is [either] not for sale or purchase of it would be cost-prohibitive” (p. 19).

This article takes a narrow focus on the tradeoff of purchasing technical data. The focus here is specifically on the government’s purchase of TDPs that facilitate competitive procurement of a system. It seeks to answer the following question:

Can the government realize lower production costs by purchasing a TDP to provide to a competitor?

To do that, the government needs to weigh the answers to two specific questions:



1. What is the price of the TDP?
2. Under what conditions can ownership of a TDP reduce the price the government pays for production?

To answer these questions, this article presents a simplified model, which explores the behavior of the economic agents involved and the implications if one relaxes the major assumptions.

The government should not assume it can achieve competition-based savings by purchasing a TDP.

Based on this analysis, one should view a TDP not as based on the costs to make it, but rather as based on a strategic decision by a firm responding to economic incentives. The price of the TDP depends on:

1. The R&D costs to replicate the information in the TDP. R&D costs are the costs incurred to develop a system prior to production.
2. The relative production costs between rival firms.
3. The quantity of systems procured.

Based on this price, the government should purchase a TDP when savings on the reduced production price are greater than the price of the TDP. The government should not assume it can achieve competition-based savings by purchasing a TDP. In cases where rival firms have higher production costs than the incumbent, the purchasing of a TDP will likely not lead to savings for the government. Conversely, in cases where rivals have lower costs of production, but R&D costs act as a high barrier to entry, the government may achieve savings through a TDP.

Analytical Framework

The government needs to understand the economic behavior of the defense contractors involved when deciding to purchase a TDP. To understand the nature of this tradeoff, this article employs a model of a game of two firms based on several key assumptions.

Assumptions for TDPs

1. **The government does not already own the data rights to the system.** In obtaining a TDP, the government is purchasing the rights to the system design in addition to information on how to produce it. In instances where the government funded R&D efforts, it would typically own the data rights and would not need to purchase them (although even here there may be some minor delivery costs).
2. **The model assumes that a TDP eliminates R&D costs for rival firms.** A TDP reduces barriers to entry in competition by allowing rival firms to compete with an incumbent by not having to conduct their own R&D effort. Importantly, rival firms can still compete without a TDP, but need to have their own R&D effort to enter production.
3. **There is no cost for producing a TDP.** The model excludes the cost of producing a TDP for simplicity. While depending on the system, TDPs would likely cost in the hundreds of thousands or very low millions, which is often minor in the context of defense procurements in the hundreds of millions or billions of dollars.

Assumptions for Firms

1. **The model is based on a duopoly.** This is a realistic assumption because DoD work is highly specialized. Only a few firms are able to produce hardware for major DoD procurements. For clarity in analysis, these are called:
 - Firm One: Incumbent that has completed an R&D effort under a previous effort.
 - Firm Two: Rival that needs to complete a separate R&D effort or receive a TDP to compete in the new contract.

For several possible reasons, Firm One may have already completed the R&D effort. The government may have previously planned to procure sole-source before deciding to compete the procurement. Firm One could have been the original producer for an item requiring a mid-service upgrade or a new contractor for sustainment.

2. **Both firms behave as profit maximizers.** Firm One will only sell a TDP if that sale increases Firm One's profit. Neither firm will bid for less than zero profit.
3. **Firms have perfect information on their own production costs, their rival's production costs, and Firm Two's R&D costs.** Both firms have enough information to accurately predict their rival's production costs (and in the case of Firm Two, R&D costs too), and hence their rival's price during the bidding process. The analytical framework presented in this section involves Firm One identifying Firm Two's price as a step in its strategy. In reality, Firm One would likely be trying to estimate Firm Two's costs, though it would not have perfect information to determine the exact costs. Additionally, both firms have enough information to accurately predict their own production costs.
4. **Zero transaction costs in the bidding process.** While transaction costs and rent seeking are important components of analyzing government behavior, the model excludes transaction costs of bidding for clarity in analysis. This article discusses the implications of relaxing these assumptions under the section Additional Complexities.

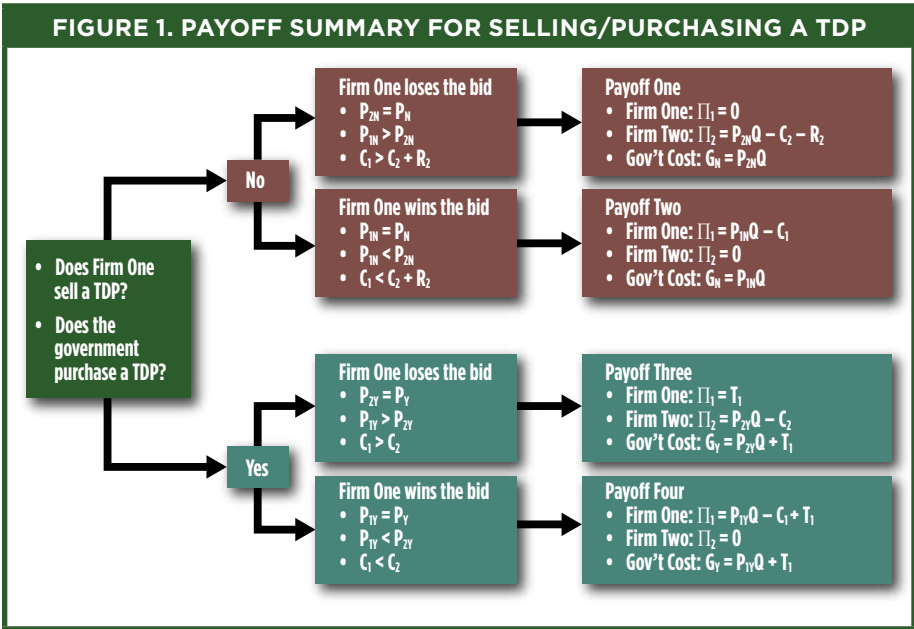
Assumptions for the Government

1. **The government sets the procurement quantity exogenously based on operational requirements.** This means firms will decide their bidding price, but not quantity. However, this quantity is large enough that marginal revenue will be greater than or equal to marginal cost for the winning firm.
2. **The government behaves as a cost minimizer when evaluating bid prices.** As a cost minimizer, the government selects the firm with the lowest price.

- 3. **The competition is a one-off and winner takes-all.** This means only one of the two firms will win the bid and be able to complete the work. This is not true for all DoD competitive procurements (e.g., continuous competition where firms compete multiple times for the share of the work).
- 4. **From the government’s perspective, both firms produce an equally acceptable product (e.g., schedule, quality).** This is an important assumption because in some cases the government will face a tradeoff between quality and price.

Model Summary

Given these assumptions, one can summarize the payoffs for a duopoly of defense contractors and the cost implications for the government. Figure 1 summarizes these payoffs.



Where:

Π = profit

P_N = unit price if Firm One does not sell a TDP

P_y unit price if Firm One does sell a TDP

Q number of systems procured

C total cost for a firm

- Includes fixed and variable cost of production
- Increases linearly as quantity increases (assuming no learning in the production process)

R cost of conducting R&D prior to production

T price the government pays for TDP

G the cost incurred by the government for procuring the system.

All independent variables are greater than or equal to zero. Subscripts in Figure 1 refer to Firm One and Firm Two (1, 2), and whether or not there is a TDP (Y, N).

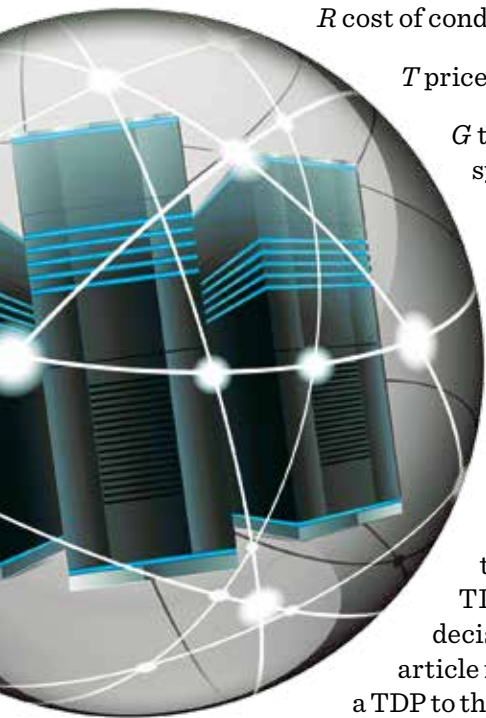
In this model, Firm One must decide whether to sell a TDP. Once Firm One makes this decision, both firms provide bids to the government. Given this scenario, Firm One should make its decision based on backward deduction of its payoffs. If Firm One decides to sell, the government must decide if it wants to buy the TDP. As with Firm One, the government should make its decision based on backward deduction of its payoffs. This article first examines a scenario where Firm One does not sell a TDP to the government. Thereafter, it examines a scenario where Firm One sells a TDP to the government.

Firm One Does Not Sell a TDP

Firm One starts by comparing its profit if it wins the bid (summarized in Equation 1) to the profit Firm Two obtains if it wins the bid (summarized in Equation 2).

$$\Pi_1 = P_1 * Q - C_1 \tag{1}$$

$$\Pi_2 = P_2 * Q - C_2 - R_2 \tag{2}$$



Firm One knows that Firm Two will not offer a bid where $\Pi_2 < 0$ and that Firm One will win the bid if $P_1 < P_2$. Firm One will identify Firm Two's P_2 and set P_1 at the highest level it can below P_2 . Firm One's bidding price will be such that $P_1 * Q \geq C_1$.

Since Firm One will set P_1 below P_2 , one can arrive at Firm Two's price. The lowest amount Firm Two will bid is $\Pi_2 = 0$, and the following two equations illustrate solving for P_2 at this point.

$$0 = P_2 * Q - C_2 - R_2 \quad (3)$$

$$P_2 = \frac{C_2 + R_2}{Q} \quad (4)$$

At $P_1 = P_2$, the following equation summarizes what Firm One's profit function becomes:

$$\Pi_1 = P_1 * Q - C_1 = \frac{C_2 + R_2}{Q} * Q - C_1 = C_2 + R_2 - C_1 \quad (5)$$

If Firms One and Two have identical cost functions, $\Pi_1 = R_2$ at $P_1 = P_2$ and $\Pi_1 < R_2$ at $P_1 < P_2$.

Several major takeaways emerge from this analysis. A major implication of Equation 5 is that Firm One's profit can be directly impacted by its rival's R&D costs. The major implications of Equation 4 when $P_1 < P_2$ (i.e., Firm One won the bid) are twofold. First, Firm One's price decreases as Firm Two's cost decreases (assuming $C_1 \leq C_2$). Second, Firm One's price increases as Firm Two's R&D costs increase. Finally, when comparing Firm Two's price (Equation 4) with Firm One's minimum-bid price in Equation 6, several implications are surmised.

$$P_1 = \frac{C_1}{Q} \quad (6)$$

Each firm's minimum bid (i.e., P_1 and P_2) increases when quantity decreases (i.e., when the government changes its quantity requirements) and/or costs increase. Firm Two can only underbid Firm One when its total costs are low enough, such that $C_2 + R_2 < C_1$.

The upshot of this analysis where Firm One does not sell a TDP are that if firms have equivalent costs, Firm One will undercut Firm Two by the amount approximately equal to the R&D costs. Firm One will earn a profit equal to price times quantity minus its costs. Firm One's revenue will be greater than its costs by an amount slightly less (because Firm One's price

needs to be less than Firm Two's) than the R&D costs Firm Two would have to incur. For Firm Two to win the bid, it must have significantly lower costs to offset the fact that it must pay for its R&D effort.

Firm One Does Sell a TDP

If Firm One does sell a TDP, both firms' profit equations change. Equation 7 summarizes Firm One's profit if it wins the bid, while Equation 8 summarizes Firm One's profit if it loses the bid.

$$\Pi_1 = P_1 * Q - C_1 + T_1 \quad (7)$$

$$\Pi_1 = T_1 \quad (8)$$

Notice that now Firm One earns revenue based on what it gains from selling the TDP to the government (as mentioned previously, assuming Firm One's R&D work occurred under a previous effort). Equation 9 summarizes Firm Two's profit if it wins the bid. Notice that it now excludes R&D costs because Firm Two now has access to a TDP.

$$\Pi_2 = P_2 * Q - C_2 \quad (9)$$

As it would have done had it not sold a TDP, Firm One compares the profit equations and identifies Firm Two's P_2 . Firm One will set P_1 at the highest level it can below P_2 to win the bid. Firm One should not use the TDP to subsidize its production costs because Firm One's assumed goal is to maximize profits and not market share.

As described earlier, since Firm One will set P_1 below P_2 , one can arrive at Firm Two's price. The lowest amount Firm Two will bid is $\Pi_2 = 0$, and the following two equations illustrate solving for P_2 at this point.

$$0 = P_2 * Q - C_2 \quad (10)$$

$$P_2 = \frac{C_2}{Q} \quad (11)$$

At $P_1 = P_2$, the following equation summarizes what Firm One's profit function becomes:

$$\Pi_1 = P_1 * Q - C_1 + T_1 = \frac{C_2}{Q} * Q - C_1 + T_1 = C_2 - C_1 + T_1 \quad (12)$$

If Firms One and Two have identical cost functions, $\Pi_1 = T_1$ at $P_1 = P_2$ and $\Pi_1 < T_1$ at $P_1 < P_2$.

The upshot for the government of having a TDP is that the lowest cost producer will win the bid in this game. Because Firm One has the profit $\Pi_1 = T_1$, if it loses the bid and $\Pi_1 < T_1$ at $P_1 < P_2$ if it wins the bid, Firm One will bid only

if $C_1 < C_2$ so that $P_1 < P_2$ and $\Pi_1 > T_1$. To have the lowest winning price, the winning firm must have the lowest costs. Previously without a TDP, Firm Two, as a profit maximizer, had to have its production costs significantly lower to offset its R&D effort.

The Price of a TDP

Having worked through the implications of Firm One either not selling or selling a TDP, one must consider the price of a TDP. One can arrive at the bounds of the TDP’s price by analyzing the conflicting cost-minimizing behavior of the government and the profit-maximizing behavior of Firm One. Table 1 summarizes the analysis presented in this section.

TABLE 1. LOW AND HIGH BOUNDS FOR THE TDP’S PRICE				
Relative Costs of Firm One and Firm Two	Firm One’s Minimum Price	The Government’s Maximum Price	Winner with TDP	Winner w/o TDP
$C_2 + R_2 < C_1$	0	$Q * (P_N - P_Y)$	Firm Two	Firm Two
$C_2 + R_2 > C_1$ & $C_2 < C_1$	$P_{1N} Q - C_1$	$Q * (P_N - P_Y)$	Firm Two	Firm One
$C_2 + R_2 > C_1$ & $C_2 > C_1$	$Q * (P_{1N} - P_{1Y})$	$Q * (P_N - P_Y)$	Firm One	Firm One

At What Price Does Firm One Sell a TDP?

Firm One sets the price to maximize profits based on expectations from Firm Two and the government. As an upper bound, Firm One’s TDP price should never exceed the government’s cost savings for purchasing a TDP, $Q * (P_N - P_Y)$ (see following section on When Should the Government Purchase a TDP?). For prices greater than this point, Firm One, though naturally desiring an infinitely positive payoff, realizes that it is cheaper for the government to contract Firm Two to develop and produce the system. Firm One would receive a payoff of zero.

As a lower bound, Firm One’s TDP price depends on Firm Two’s production costs. When $C_2 + R_2 > C_1$ but $C_2 < C_1$, Firm One should set the price of the TDP such that:

$$T_1 > P_{1N} Q - C_1$$

(13)

This price ensures that Firm One’s payoff of the TDP is greater than the payoff lost from not producing systems. When $C_2 > C_1$, Firm One should set the price of the TDP such that:

$$T_1 > Q * (P_{1N} - P_{1Y}) \tag{14}$$

This TDP price ensures that Firm One’s payoff from the TDP more than compensates for its lower production price.

Finally, if $C_2 + R_2 < C_1$, Firm One knows it will lose the bid, and should be willing to sell a TDP for any price the government would be willing to accept, which would fall in the range where $0 < T_1 < R_2$ (this assumes that Firm Two passes cost savings from having a TDP on to the government).

When Should the Government Purchase a TDP?

Similar to how Firm One made its decision, the government should work through backward induction to examine the payoffs (i.e., its costs) and select the cost-minimizing option. Importantly, even if Firm One would like to sell a TDP, it does not necessarily make sense for the government to purchase it.

Since the government finds either firm’s product equally acceptable and makes its decision based on price, one can summarize the government’s decision to purchase a TDP as depicted in Equations 15 and 16:

$$P_Y * Q + T_1 \leq P_N * Q \tag{15}$$

$$T_1 \leq Q * (P_N - P_Y) \tag{16}$$



Equation 15 is the cost to the government of the two options for procuring the system: price times quantity plus the TDP if it purchases one compared to a presumably higher price times quantity without purchasing a TDP. Equation 16 means that the government should never pay more for a TDP than the cost savings it obtains by paying P_Y instead of P_N . The upshot from Equation 16 is that as quantity increases, the maximally acceptable price of the TDP can increase as well.

The government, as a cost minimizer, should apply the decision rule in Equation 16 to its four distinct payoffs as shown in Figure 1. The most important aspect of this is using a TDP to go from Payoff Two ($G_N = P_{1N}Q$) to Payoff Three ($G_Y = P_{2Y}Q + T_1$) because in this case, the government can successfully utilize a TDP to move production to a lower cost producer.

Payoffs One and Four are less important because the TDP does not cause the production to switch from one firm to another. In Payoff One ($G_N = P_{2N}Q$), Firm Two's production and R&D costs are low enough to underbid Firm One. The government should purchase a TDP in this instance only if $T_1 < R_2$ and Firm Two is willing to pass these savings on to the government.

Payoff Four is likely a case where the government should be indifferent whether it purchases a TDP. In this instance, Firm One's minimum price equals the government's maximum price. This implies that any savings the government achieves from lower production costs would be negated by the price it pays for the TDP.

Additional Complexities

The focus of the model presented in the preceding section is to illustrate the fundamental strategic options and behavior of Firm One as well as the government and Firm Two. However, this model is a simplification of reality. This section discusses various complexities of the model, including a TDP as a substitute for R&D, the behavior of the government, and behavior of firms.

Research and Development and a Technical Data Package

For simplicity, the analytical framework presented earlier in this article relies on the assumption that a TDP is a perfect substitute for a firm's own R&D effort. However, this is not entirely accurate, in part because a TDP does not communicate all production knowledge. At the very least, a firm would need to expend some R&D effort to customize the information in a TDP to its own production facility. This could include items such as production set up, accuracy of machines, training personnel, and obtaining

relevant certifications. Some projects require much more than a TDP. For instance, in the late 1970s Williams Research Corporation designed the F107 cruise missile engine that the U.S. Air Force wanted to be coproduced with Teledyne Continental Aircraft Engines (CAE). The Air Force required Williams “to provide Teledyne CAE with all of the knowhow necessary to produce the engine” (Leyes & Fleming, 1999, p. 414), which was beyond the scope of a TDP. Additionally, third-party firms provide a service of deriving information from a TDP. One such company states on its Web site that they “support the process [of] taking engineering designs and technical data packages (TDPs) to optimize the manufacturing/production of a part/component/system” (Strata, n.d.).

Further, the firm selling the TDP has a large degree of control over its format and content. This firm, seeking to maximize profits, has an incentive to make the TDP as useless to a rival as possible. These and similar considerations should lead the government to ensure that the TDP content and format are carefully specified so that the TDP will serve its intended purpose of transferring relevant data to the other firm.

However, the basic dynamic behind the model remains the same, although now the TDP serves to reduce rather than eliminate a rival’s R&D costs. Firm Two would have to incur some R&D costs even with a TDP. Firm One would be able to undercut Firm Two by approximately this amount provided their production costs are equal.

The model presented in the previous section assumes that the government does not own the data rights and it obtains these when it purchases the TDP. In some cases, the government may already own the data rights (e.g., it may have paid for the development effort) even though it has not purchased a TDP. For more information, see Defense Federal Acquisition Regulation Supplement (DFARS) 252.227-7013 and DFARS 252.227-7015 (DoD, 2014b, 2014c).

However, some of the dynamics of the model remain relevant even if the government owns the rights. For instance, the firm producing the TDP could seek ways to increase the cost of the government’s TDP purchase, such as proposing an excessive number of senior-level engineers to develop the package and make it more complex than required. While presumably not as large as the price for the data rights, this increase would be significant enough for the government to consider.

During the sustainment phase of a program, the government may be able to reverse engineer an item (DoD, 2006) in some cases instead of purchasing a TDP.

Another simplification is that the model relies on an assumption that Firm Two conducts its own independent R&D effort if it does not have a TDP. Alternatively, the government could pay a firm other than Firm One to develop a TDP, and provide this to Firm Two. From the government's perspective, this method would ensure the bidding process better reflects rival firms' production costs. In the context of the analytical framework presented earlier in this article, the lowest amount Firm Two can bid is no longer $C_2 + R_2$, but rather C_2 . The government could also pay less for this option because a third-party firm, not bidding for production, does not have incentives to use a TDP as a means to increase its production price. The cost of research could be even lower than the original development, because the nature of the solution is now known.

During the sustainment phase of a program, the government may be able to reverse engineer an item (DoD, 2006) in some cases instead of purchasing a TDP. It could do this either through one of its depots or through a contractor with the Replenishment Parts Purchase or Borrow Program (Defense Logistics Agency, n. d.). Using a depot would be analogous to the government paying a third-party firm as described previously. Using a contractor would be similar to retaining $C_2 + R_2$. This is because even though the contractor pays the cost to reverse engineer the item under this program, a profit-maximizing firm would presumably later recoup these costs in its sales to the government.

Government Behavior

Government is not a monolithic force. Rather, it is an organized collection of publically funded individuals who face externally imposed budget constraints and their own set of incentives, as a large body of public choice literature has pointed out (e.g., Buchanan & Tullock, 1962). For weapons

procurement, the decision-making body is composed of individuals in acquisition program offices throughout DoD. These individuals face time constraints on when they receive funding from Congress via the DoD bureaucracy.

The analytical model presented earlier in this article does not consider time even though the program office's funding profile by fiscal year matters. For instance, program managers may believe that they have ample funding to purchase a TDP now, but believe they will have less funding in the future to procure production units. In this case, the program office may purchase a TDP when $P_Y Q < P_N Q$ but $P_Y Q + T_1 > P_N Q$ (i.e., paying more overall, but reducing future costs). Conversely, the program office could decline to purchase a TDP when $P_Y Q + T_1 < P_N Q$ for several possible reasons. The program office may face a budget constraint in which it lacks funds currently, but will have ample funding in future years.

Another problem is a principal-agent problem, where the incentives of the program managers are not well aligned with those of taxpayers, or even DoD leadership. One possibility could be budget-maximizing bureaucrats (e.g., Niskanen, 1975). In this case, the program office could be attempting to increase its budget and hence the prestige of its members, thereby resulting in the program office deliberately increasing its budget by selecting a more costly option. Another example could be one of externalities leading to poor incentives to reduce costs. The responsible program manager could be anticipating leaving the program office before savings from a TDP are realized. If the program manager is not penalized in the present time by the future higher costs, the manager lacks good incentives to work for a TDP even though this would benefit DoD and potentially the taxpayer by saving funds.

Behavior by Firms

The analytical model presented earlier has three major underlying assumptions that impact the price that firms would bid: profit-maximizing behavior, zero transaction costs, and perfect information. Relaxing the profit-maximizing assumption may lead to a lower bid if firms seek to cover only variable costs as opposed to fixed costs. While defense firms should behave as profit maximizers in the long run across a portfolio of systems, they may not behave as profit maximizers for individual programs in the short run. For instance, a firm may have some large fixed costs, such as excess plant capacity or highly specialized staff, which are temporarily underutilized, but needed for long-term profitability. In cases like this, the firm may bid a price to cover only its variable costs, but not its fixed

costs. A possible example of this is Boeing bidding very aggressively on the replacement of aerial tankers to exclude rival Airbus from one of its markets (Thompson, 2011).

The analytical framework assumes zero transaction costs in the bidding process. However, firms could engage in additional activities other than the bidding process to win. For example, this could include expending considerable resources on lobbying and/or contesting lost bids through political mechanisms. Economists Christopher Coyne and Thomas Duncan (2013) contend that in striving to win the competition to produce the F-35, “Boeing and Lockheed Martin engaged in rounds of mergers and acquisitions to expand their political base” (p. 426). Economist Gordon Tullock (1967) has pointed out that parties competing to be a monopolist can bid up expected profits, eliminating their consumer surplus. Since firms are profit maximizing and would exit the industry if their profits are less than zero, one would expect that these costs would eventually get passed on to the government, possibly through higher unit prices for the government. In the context of the model, one could even add a term for bidding costs—which means the losing firm would have a negative payoff, instead of zero.

While defense firms should behave as profit maximizers in the long run across a portfolio of systems, they may not behave as profit maximizers for individual programs in the short run.

While the model assumes perfect information, this is not always a realistic assumption (for instance, Hayek [1945] contains an argument on information contrary to neoclassical economics). In the context of DoD procurement, firms typically know only their costs, what government program offices are willing to share regarding the acquisition plan, and the quantity of systems desired. Knowing the acquisition plan and quantity of systems is imperative, because as the model suggests, the price of the TDP increases as the number of systems procured increases.

Imperfect information on a rival's costs would benefit the government if firms would offer lower bids than absolutely necessary. The purpose of these lower bids is to make sure the firm gives itself enough price margin to successfully undercut its competitor's bid. Conversely, relaxing the information assumption for a firm's own production costs (i.e., the firm is not sure of the accuracy of its own production costs) could lead firms to offer a higher bid. The purpose of this is for the firm to have a reserve to meet potential cost overruns during production.

Firms, realizing that the government does not have perfect information on contractors, could attempt postcontract opportunism. The bidding firms could provide low bids based on overly optimistic cost estimates. This could lead the government to pay more than it anticipated in production costs. One solution would be for the government to conduct independent cost studies on firms' bids for realism. However, because cost estimators also have limited information, this is not a perfect solution. Another solution, especially if the government lacks even enough information for independent studies, would be to ensure a credible threat of retaliation in the contract to incentivize firms to provide accurate bids. For instance, the government could maintain an industrial base with multiple firms, cancel the contract if costs went beyond a certain threshold, and then rebid the effort. This is one possible explanation for why DoD supports two independent shipyards to construct DDG-51 Arleigh Burke-class destroyers, awards contracts to small businesses, and prefers commercial off-the-shelf hardware to customized military versions.

Conclusions

The government should purchase a TDP if the price of the TDP is less than the savings resulting from a lower production price. It should tend not to purchase a TDP while blindly assuming it will minimize costs through competition. One can think of a TDP as a barrier to entry. A TDP has the most dramatic effect for the case in which it is very costly to replicate its information through an R&D effort, but a rival firm has significantly lower production costs. In this instance, making the TDP available to the rival firm serves to move production to lower cost producers. A TDP may be relevant in other cases as well. If a rival firm can undercut the incumbent even with its own R&D effort, providing that rival firm with a TDP may save the government funds if the rival firm is willing to pass on a sufficient portion of its savings by accepting a TDP from the government. While not necessarily cost-minimizing from the government's perspective, a TDP could benefit

the government in cases where funding is readily available now, but less certain in the future. Finally, recognizing that firms may use a TDP as a barrier to limit competition, the government could have a third party, not involved in the production process, conduct R&D.

The government should purchase a TDP if the price of the TDP is less than the savings resulting from a lower production price.

The key takeaway from the model presented in this article is that a profit-maximizing firm will price a TDP based on its production costs compared to its rivals, the cost to produce the content of a TDP through an independent R&D effort, and the number of systems procured subject to the considerations covered under the section Additional Complexities. The government should recognize that the price it pays for a TDP depends on these economic variables: a TDP's price is not simply the cost to produce the TDP.

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Biography



Mr. Nicholas J. Ross is currently an analyst at Tecolote Research, Inc. He has worked on cost estimates for Marine Corps Systems Command, Office of Naval Research, Naval Sea Systems Command, and the Federal Aviation Administration. Mr. Ross earned an MA in Economics from George Mason University, where he published a paper on the provision of naval defense in the early American republic. He also holds a BS in Economics and History from Mary Washington College.

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BALANCING

Incentives and Risks

in Performance-Based Contracts

 *Maj Christopher P. Gardner, USAF, Jeffrey A. Ogden,
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Performance-Based Life Cycle Support (PBL) as a sustainment strategy for weapon systems has been mandated by the Department of Defense (DoD) and employed by acquisition and contracting professionals in both government and private industry. Despite its apparent success, DoD implementers of PBL often face an inherent conflict: the PBL goal of developing long-term partnerships that encourage investment from commercial partners is best achieved through lengthy, guaranteed contracts—but such contracts increase the DoD's risk in an environment that is intended to transfer more risk to the contractor. This exploratory research examines issues associated with the type and length of PBL contracts, addressing the question of how the DoD can balance PBL contracts mitigating operational and financial risks while simultaneously building long-term partnerships that encourage investment from commercial contractors. The results reveal five areas in which the government should focus its efforts to improve PBL implementation.

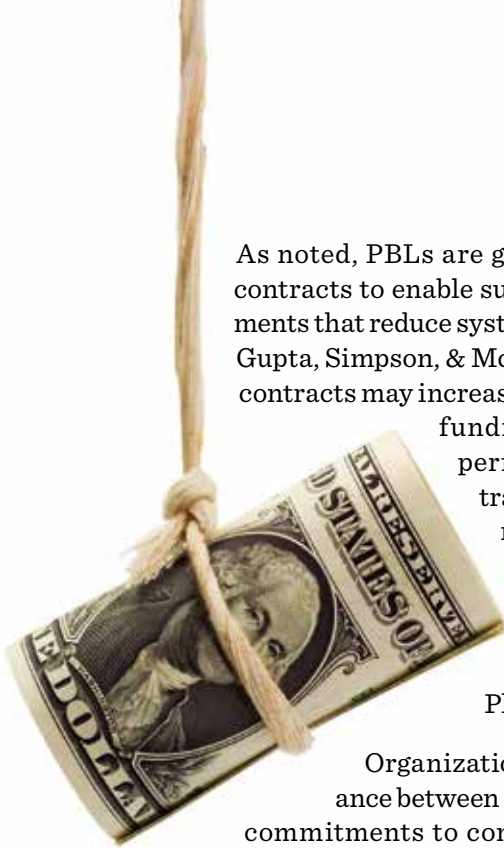
Keywords: *performance-based life cycle support, case study, PBL, contracting*

The current preferred product sustainment strategy for improving weapon systems readiness within the Department of Defense (DoD) is known as performance-based life-cycle support (or Logistics; PBL) (Acquisition Community Connection [ACC], 2013; DoD, 2013). Unlike traditional strategies, PBL shifts “from buying iterative discrete quantities of goods and services (transactional logistics) to acquiring sustainment via top-level outcomes” (Fowler, 2009, p. 10). By focusing on the purchase of outcomes rather than transactions, PBL strategies incentivize the providers to invest in their logistics infrastructure to reduce total system life-cycle costs while simultaneously meeting system performance and support (Kim, Cohen, & Netessine, 2007; Randall, Nowicki, & Hawkins, 2011).

Background

Under the old transactional strategy, when a firm contracted to supply, for example, aircraft parts, they profited from every part sold, but also had no inherent incentive to improve the product. The incentive was to maximize the sale of parts. Under a PBL strategy, that company may now be responsible for providing availability or up-time. This change shifts that company’s incentive away from volume and towards quality. Paying the contractor a fixed price for availability encourages them to reduce the amount of parts used, increasing their margins (Geary & Vitasek, 2008). Some argue that PBL has, “for the first time in the history of DoD ... aligned the interests of each link in the chain with the end-user—the warfighter” (Vitasek, Geary, Cothran, & Rutner, 2006, p. 7). A well-structured PBL contract maintains or improves performance, lowers costs to the government, and increases profits for the supplier (Randall, 2013).

PBL-based contracts are intended to shift risk away from the customer and move it to the supplier while simultaneously increasing the supplier’s potential for reward. In traditional support strategies, the risk rests with the government. By contracting for components (for instance, purchasing parts), the government risks increased failure rates, unavailability of parts, and obsolescence. To protect against these risks, the government typically increases purchase volume thereby increasing safety stock (Openshaw & Riffle, 2006). By purchasing a capability, the customer seeks to share these risks with the supplier. Suppliers can be incentivized to take on these risks in several ways, including a pricing model, rewards for reaching targets, provisions for exit criteria for both customer and supplier, work-scope flexibility, and finally, contract length (Geary & Vitasek, 2008).



As noted, PBLs are generally seen as providing long-term contracts to enable suppliers to invest in systemic improvements that reduce system costs over the long term (Berkowitz, Gupta, Simpson, & McWilliams, 2004–2005). However, such contracts may increase the DoD's risk through uncertainty of funding, operational tempo, and supplier performance (Mahon, 2007). While contracts of shorter term lengths may reduce risks for the government, the supplier's incentive to make significant up-front investments, providing long-term benefits for the system, is also reduced (Gupta, Eagan, Jones, & Platt, 2010).

Organizations face the challenge of finding a balance between mitigating their own risks while making commitments to commercial contractors that encourage affordable, long-term support. No study has yet been undertaken to broadly examine if DoD's current contracting strategies are achieving this balance. This research investigates the factors most important to decisions for PBL contract type and length, examining contracting trends in past and current PBL programs, and garnering the opinions of subject matter experts (SMEs) in both DoD and private industry. It seeks not to examine whether PBL is a viable sustainment technique, but rather to identify what steps can be taken to contractually improve PBL structure by moving the government closer to achieving the necessary balance. To address these issues, the following research question was investigated:

How can the DoD ideally balance PBL contracts to mitigate operational and financial risks while simultaneously building long-term partnerships that encourage investment from commercial contractors?

Subsequently, the authors established several investigative questions to guide the research and to frame the methodology:

1. What types and lengths of PBL contracts have proven most successful and effective to date?
2. What risks and other criteria most frequently play a role in determining PBL contract type and length?

3. Are contracts adequately structured to consistently meet the PBL goal of establishing long-term partnerships?
4. Are PBL contracts adequately structured to consistently provide incentives for contractors to make cost reductions in system support?
5. How satisfied are PBL experts in both DoD and private industry with the government's risk aversion in PBL contracts?
6. Would any significant benefits be gained if the maximum contract length allowed by the Federal Acquisition Regulation (FAR) were increased?
7. Are award term and option year contracting strategies being used effectively, and should their use continue in a lesser, similar, or greater capacity?
8. Should Working Capital Funds (WCF) be used more extensively in PBL programs?
9. Does a PBL agreement's place among the "Four Stages" (Vitasek et al., 2006, p. 7) of PBL have any impact on contract length decisions?

Literature Review

PBL Partnerships

The processes of acquisition and sustainment in the DoD have been continually evolving. The focus has shifted from organic development of technology emphasizing weapon effectiveness to commercial technology and sustainment strategies that increase performance while reducing costs over the life of systems. The DoD seeks to gain the most efficient and effective performance of systems throughout their entire life cycles and to align the goals of all involved organizations for the duration of the programs (Berkowitz et al., 2004–2005).

The DoD's use of PBL has shifted in recent years. In 2008, with the publishing of interim guidance for *Operation of the Defense Acquisition System* (DoD, 2008), the DoD altered PBL, redefining it as performance-based life-cycle support. This guidance stated that "Performance-Based Life-Cycle

Product Support represents the latest evolution of Performance-Based Logistics...” (DoD, 2008, p. 29). The DoD maintains that the two are synonymous and retains the PBL acronym (DoD, 2013).

Indeed, the Assistant Secretary of Defense for Logistics and Materiel Readiness published a memorandum titled “Performance Based *Logistics* Comprehensive Guidance” [italics added] at the end of 2013. Likewise, the academic literature, as demonstrated in two of the premier logistics journals—the *Journal of Business Logistics* and the *International Journal of Physical Distribution and Logistics Management*—published articles that still refer to PBL with logistics in the title (Glas, Hofmann, & Eßig, 2013; Randall et al., 2011). Finally, DoDI 5000.02, the most current version of the DoD’s guidance on the operation of its acquisition system, requires program managers to “Employ effective performance-based logistics ... in developing a system’s product support arrangements...” (DoD, 2015, p. 113). Since the DoD finds the two concepts synonymous, this work will use them interchangeably. The DoD acquisition community defines PBL (ACC, 2013) as:

An outcome-based product support strategy for the development and implementation of an integrated, affordable, product support package designed to optimize system readiness and meet the warfighter’s requirements in terms of performance outcomes for a weapon system through long-term product support arrangements with clear lines of authority and responsibility. (para. 4)



This definition points to the establishment of long-term support arrangements (ACC, 2013). The literature suggests this as being an essential element of a successful PBL (Berkowitz et al., 2004–2005; Gupta et al., 2010; Randall, Pohlen, & Hanna, 2010). But mere length of time does not necessarily constitute a partnership (Lemke, Goffin, & Szejcowski, 2003). The literature clarifies that these long-term relationships extend not only beyond simply the length of the contract, but also in the development of partnerships

(DeVries, 2005; Geary & Vitasek, 2008; Geary, Koster, Randall, & Haynie, 2010; Starks, 2004–2005; Vitasek et al., 2006). According to Lambert, Emmelhainz, and Gardner (1996, p. 2), “A partnership is a tailored business relationship based on mutual trust, openness, shared risk, and shared rewards that yields a competitive advantage, resulting in business performance greater than would be achieved by the firms individually.” Research suggests that organizations should look for ways to develop partnerships and integration to increase value (Ogden, Petersen, Carter, & Monczka, 2005). In this light, partnerships are often viewed as centrally important to the success of PBL programs (Randall et al., 2011; University of Tennessee, 2012). The core of the PBL strategy involves capitalizing on integrated logistics chains and public/private partnerships (DoD, 2013).

Contractual relationships that are largely transactional, involving minimal integration of operations between DoD and smaller support providers, are generally not considered to be performance-based contracts.

Partnerships can differ significantly and not all business relationships are truly partnerships (Daugherty, 2011). The same can be said of PBL within the context of DoD contracts. Contractual relationships that are largely transactional, involving minimal integration of operations between DoD and smaller support providers, are generally not considered to be performance-based contracts. In contrast, DoD and major defense contractors, such as Lockheed Martin and Boeing, increasingly enter into performance-based accords that display several characteristics of partnerships (Goure, 2009; Office of the DoD Inspector General, 2006). The rationale for entering into partnerships is based on perceived benefits (Daugherty, 2011) and, in fact, firms should enter into a partnership only if they cannot achieve said benefits without the partnership (Lambert & Knemeyer, 2004). The expected benefits form the compelling reasons to partner. The four primary reasons are (a) asset/cost efficiencies, (b) customer service, (c) marketing advantage, and (d) profit stability/growth. Although it is unlikely that the drivers will be the same for both parties, a sturdy partnership requires that they be strong for both (Lambert, Knemeyer, & Gardner, 2004).

The DoD partners to improve service to its customers—the warfighters—and to improve asset performance and cost efficiencies (Kobren, 2009). By employing the PBL strategy, DoD aims not only to better meet the needs of

the operational end-users by improving system performance and readiness, but to minimize the total system life-cycle costs and logistics footprints associated with those systems (DoD, 2007). On the other hand, firms are driven to partner with the DoD by the potential benefits of profit stability/growth and marketing advantage (Hypko, Tilebein, & Gleich, 2010). Profitability is enhanced by long-term volume commitments for products, services, or both (Gupta et al., 2010; Ng & Nudurupati, 2010; Noordewier, John, & Nevin, 1990).

Lambert et al. (1996) classify partnerships into three types, based on the level of commitment and integration of the relationships. Type I is a just-above-arm's-length relationship, Type III is the highest level of partnership. PBL programs are weapon systems-unique (DoD, 2013) so it could be argued that programs exist at all three levels (Geary & Vitasek, 2008). However, most PBL contracts between the DoD and the major defense contractors fit into the category of Type II partnerships, defined as follows: "The organizations progress beyond coordination of activities to integration of activities ... multiple divisions and functions within the firm are involved in the partnership" (Lambert et al., 1996, p. 3).

Risk

Inherent in any discussion of contracts is the sharing of risk. Firms are most concerned with financial risk, that is, ensuring that they will have enough business to realize an adequate return on investment (ROI). Vendors seek to ensure profitability and reduce financial risk through longer contracts, but also weigh their risks in determining the level of service they are willing and able to provide.

The government's prime concern is operational risk, or the ability to meet mission objectives (Doerr, Eaton, & Lewis, 2005). Contracting or outsourcing support puts certain aspects of the mission in the hands of the supplier, making the upstream of the supply chain of concern to the government (Giunipero & Eltantawy, 2004). Another aspect of risk in establishing a PBL is to ensure that the customer requirements (the demand side of the supply chain) can be met by the terms of the contract and the supplier (Wagner & Bode, 2008). The length of a contract that DoD is willing to grant is often directly related to the amount of operational risk assumed by the commercial support provider. Doerr et al. (2005, p. 180) propose that "when commercial sector vendors assume less (measurable) operational risk under a PBL contract, the term of that contract should be less." This implies that when vendors take on greater risk, the government should offer a longer contract. The DoD is also concerned with financial risk. Flexibility, affordability, and support-cost reduction are important aspects of PBL

(Boyce & Banghart, 2012; DoD, 2011; Randall et al., 2010). DoD contracting behavior is often tempered by the risk of being unable to divert funds when changes to the mission require the use of different weapon systems. Economic uncertainty and potential price adjustments are also taken into consideration by contracting officers who craft long-term deals (General Services Administration, Department of Defense, & National Aeronautics and Space Administration, 2005).

It is important to understand the impact that financial and operational risk has on PBL contract decisions. Doerr et al. (2005) posit that by lowering financial risks for the supplier, multiyear contracts enable those suppliers to accept greater operational risks. Long-term relationships are at the core of a successful PBL strategy because multiyear contracts may be the best incentive for vendors to provide the greatest weapon systems support possible (Keating & Huff, 2005). It is argued that firms may prefer long-term relationships with lower, but sustained profit generation versus short-term contracts with higher margins. “Profit earned over an extended period, however, is better aligned with the longer strategic goals of a firm, and therefore exerts greater influence on shaping contractor performance” (Stevens & Yoder, 2005, p. 32).

Advantages and Disadvantages of Long-Term Contracts

Intrinsic advantages and disadvantages accompany long-term contracts, whether they are in the public or private sectors. Monczka et al. (2008) summarized the literature, listing some rewards and drawbacks that organizations can experience when executing long-term contracts (Table 1).

TABLE 1. ADVANTAGES AND DISADVANTAGES OF LONG-TERM CONTRACTS	
Potential Advantages:	Potential Disadvantages:
<ul style="list-style-type: none">Assurance of supplyAccess to supplier technologyAccess to cost/price informationVolume leveragingSupplier receives better information for planning	<ul style="list-style-type: none">Supplier opportunismSelecting the wrong supplierSupplier volume uncertaintySupplier foregoes other businessBuyer is unreasonable

Note. Adapted from Monczka et al. (2008)

Contract Structure and Incentives

In addition to contract duration, consideration must be given to how the vendor will be paid and how to incentivize performance. DoD support contracts typically fall into one of two broad categories: Cost-Reimbursable or Fixed Price (General Services Administration et al., 2005).

While a *Fixed Price* contract guarantees that a vendor will be paid a set price regardless of the costs incurred, a *Cost-Plus* contract is expense-based: when the contractor completes the agreed-upon work, the compensation received is equal to costs plus a bonus (either award or incentive fees) provided that the expenses are allowable and reasonable. The major determinant in choosing between a Cost-Plus and a Fixed Price contract is the degree of pricing risk present in the support cost (Defense Acquisition University [DAU], 2013). Such risk is higher during the early phases of program development and deployment, when costs are less certain, thereby making Cost-Plus contracts more appropriate. In general, however, the contracting objective is to eventually achieve a Fixed Price contract in conformance with the PBL concept of buying defined outcomes at a defined price (DoD, 2013).

Consideration must also be given to the types of incentives that will be utilized in a PBL contract (Edison & Murphy, 2012). For vendors to earn the rewards associated with PBL incentives, they must meet or exceed the contractual metrics for performance and/or support (DAU, 2013), depending on specific contract requirements. For a more thorough discussion of contract structures and incentives, see Geary et al. (2008).

The Four Stages of PBL

The “Four Stages” is a method of classifying PBL arrangements according to their “level” of strategy implementation (Vitasek et al., 2006, p. 7). Stage 1 describes support at the component level, Stage 2 describes support at the major subsystem level, Stage 3 deals with the weapon systems platform level, and Stage 4 assures mission availability/support at the system level. The Four Stages are frequently used to describe the wide range of PBL possibilities and the potential evolution of such programs. While the Four Stages do not exist to provide any sort of prescription for PBL contract structure, the possibility of conceptual correlations between the different stages, and varying types and lengths of contracts warrant investigation.

Methodology

Research Design

This exploratory research utilized case studies of existing PBL programs and interviews with PBL experts to gain a greater understanding of those factors having a significant impact on contract type and length, the degree to which contract length has been an issue during implementation, and how this information can apply to future decision making. Case studies and SME interviews were selected as appropriate methods for this research because the study asked several “how” and “what” questions that required an exploratory investigation (Yin, 2009). Choosing the best contracting methods for PBL programs is often based on opinion and difficult to support with empirical data. Case studies provide insight into lessons learned by those involved with high-profile PBL initiatives. Data were gathered at two levels or units of analysis.

The first unit of analysis, the program level, incorporated a representative sample of PBL programs as case studies. Representatives of commercial programs, primarily at the system or platform level, were solicited for support among the Army, Air Force, and Navy. Interviews were conducted with



program personnel in both DoD and private industry. Analysis conducted at this level sought to reap historical information and expert opinions associated with PBL programs at their points of execution.

The second unit of analysis, the DoD level, incorporated an executive-level view of PBL implementation within government. Interviews were conducted with PBL SMEs not associated with specific programs to broaden the perspectives on contract length issues. An SME was defined as any government or private sector representative who had at least 5 years' experience working closely with, overseeing, or evaluating multiple programs. Most SMEs offered opinions based on conclusions they had drawn as a result of working on multiple programs, thereby adding a degree of veteran opinion.

A critical question regarding interviews is: how many interviews need to be conducted? The gold standard for determining this number is saturation (Guest et al., 2006). Saturation is the point at which additional interviews no longer provide fresh ideas or information (Creswell, 2014; Davis-Sramek & Fugate, 2007). This number is generally low, with a good approximate for qualitative research being 10 or fewer (Corbin & Strauss, 2008; Guest et al., 2006).

Data Collection and Analysis

The interview questions were designed to answer the investigative questions and illuminate the areas of PBL contract structure in which improvements might be made. Interview questions were divided into four sets, corresponding with the four categories of respondents:

1. DoD personnel associated with case study programs
2. Private industry personnel associated with case study programs
3. DoD PBL SMEs
4. Industry SMEs

Ultimately, six PBL programs were studied, resulting in interviews with 12 individuals. Additionally, interviews were conducted with six SMEs for a project total of 18 individuals. The specific programs studied and affiliations of personnel who contributed data to this research are listed in Tables 2 and 3.

TABLE 2. CASE STUDY PROGRAMS SELECTED AND ASSOCIATED PERSONNEL INTERVIEWED			
PBL Program	Organizations Represented by Personnel Interviewed	Type of Contract ^a	Length of Contract ^b
C-17 Globemaster III Sustainment Partnership (GSP)	<ul style="list-style-type: none">• U.S. Air Force Acquisition Program Office, Logistics Management• Boeing Company, Business Development Dept.	Combination of Firm Fixed Price Award Fee and Cost Plus Incentive Fee	<ul style="list-style-type: none">• PBL contract began in 1998• Current contract period: 2004–2008• 5-year base with 3 option years• Current Justification and Approval (J&A) lasts until 2011^c
T-45 Goshawk Contractor Logistics Support	<ul style="list-style-type: none">• U.S. Navy, Naval Air Systems Command (NAVAIR), Logistics Management Integration Dept.• L-3 Communications Corp., Program Management	Firm Fixed Price with Over & Above Contract Line Item Numbers & performance bonuses	<ul style="list-style-type: none">• Current contract period: 2004–2008• 1-year base with 4 option years
High Mobility Artillery Rocket System (HIMARS) Life Cycle Contract Support (LCCS) I/II	<ul style="list-style-type: none">• Lockheed Martin Corp., Missiles & Fire Control• U.S. Army, LCCS Team, Precision Fires Rocket & Missile Systems Project Office	<ul style="list-style-type: none">• Firm Fixed Price with Incentive Fee• Cost-Plus Fixed Fee for contingency deployments	<ul style="list-style-type: none">• LCCS I covered 2004–2007• LCCS II will cover 2008–2010• 1-year base plus option years (both contracts)

TABLE 2. CASE STUDY PROGRAMS SELECTED AND ASSOCIATED PERSONNEL INTERVIEWED, CONTINUED

PBL Program	Organizations Represented by Personnel Interviewed	Type of Contract^a	Length of Contract^b
E-8 Joint Surveillance & Target Attack Radar System (JSTARS) Total System Support Responsibility (TSSR)	<ul style="list-style-type: none"> Northrop Grumman Corp., Aerospace Prime Contractor (3 personnel) 	Cost Plus Award Fee and Award Term	<ul style="list-style-type: none"> PBL contract began in 2000 as 1-year base with 5 option years J&A period of 22 years^c Contract years have been negotiated up to 2010 (award term)
F/A-18 Hornet F/A-18 Integrated Readiness Support Teaming (FIRST)	<ul style="list-style-type: none"> U.S. Navy, F/A-18 and EA-18G Program Office, Office of the Director of Logistics and Naval Inventory Control Point (NAVICP) 	Firm Fixed Price, current contract combines 2 contracts for NAVAIR & NAVICP	<ul style="list-style-type: none"> Current contract period: 2006–2015 5-year base with single 5-year option
F-117 Nighthawk Total System Performance Responsibility (TSPR) & Total System Support Partnership (TSSP)	<ul style="list-style-type: none"> Lockheed Martin Corp., Strategic Plans & Sustainment Integration 	<ul style="list-style-type: none"> Cost Plus Incentive Fee “Stabilized Funding” for first 8 years 	<ul style="list-style-type: none"> TSPR period: 1999–2006 (5-year base with 3 option years) TSSP period: 2007–2008

Note. ^a Refers to the contract's present or last documented form

^b Dates refer to fiscal years

^c J&A = Justification and Approval from Congress for sole source

TABLE 3. PBL SUBJECT MATTER EXPERTS INTERVIEWED		
Department of Defense		Private Industry
Organizational Affiliations of Participants	<ul style="list-style-type: none">• Directorate of Innovation & Transformation, Headquarters United States Air Force	<ul style="list-style-type: none">• Booz Allen Hamilton, Inc.—Senior Associate
	<ul style="list-style-type: none">• Naval Air Systems Command (NAVAIR)—Logistics Integration,• Naval Inventory Control Point (NAVICP)—Supply Chain Solutions Division *	<ul style="list-style-type: none">• Lockheed Martin Corp.—Corporate Focused Logistics
	<ul style="list-style-type: none">• Air Force Materiel Command (AFMC)—Acquisition Logistics	

* One interview conducted with two personnel at NAVICP

The subsequent analysis organized the data into the four categories based on the participants’ affiliations. Responses for each interview question were consolidated, matched according to respective investigative questions, and examined for similarities and differences. This was achieved by searching for key words, themes, and implications communicated by the interview participants. Conclusions were drawn based on these apparent themes, common views, and key opinions of the interviewees.

Data Analysis and Findings

This section is organized around those investigative questions utilized during the case study interviews. Implications of these findings and their influence on the overall research question will be addressed in the conclusions and recommendations section.

Question 1: What types and lengths of PBL contracts have proven most successful and effective to date?

Interview participants at the program level were asked to express their (or their organizations') degree of satisfaction with the type and length of the PBL contract in question, and to assess the contract's effectiveness in the context of type and length. Interestingly, in all three cases where both public- and private-sector representatives were interviewed for the same program, both sides were in agreement on the suitability of the type and length of the contract, whether good or bad.

A consistently high level of satisfaction with contract length was found among programs that had contracts with a 5-year base, followed by option years or award terms.

Results for Contract Length

A consistently high level of satisfaction with contract length was found among programs that had contracts with a 5-year base, followed by option years or award terms. Respondents in these cases expressed that the contract length allowed for an appropriate amount of risk sharing and ROI. One interviewee noted that the option years strengthened the arrangement by allowing flexibility for contract changes while extending the agreement into the future. This was a recurring finding throughout the research. The most notable case of dissatisfaction from both government and contractor involved a contract with a 1-year base and 4 option years. They agreed it was too short, because it was limited to 5 years by the FAR requirements for service contracts. A 10-year contract consisting of a 5-year base with 5 option years was preferred. The government interviewee argued that the benefits of a longer contract would outweigh the costs and the contractor agreed, contending that a longer agreement would allow for more creativity in managing spares.

Results for Contract Type

A consistently high level of satisfaction with contract type was found among programs with Firm-Fixed Price (FFP) contracts, which supports the idea that FFP is the desired end-state for PBL contracts. One contractor expressed some dissatisfaction with the current Cost Plus Award Fee contract structure on their program, noting that while these Cost-Plus style of contracts were appropriate in earlier years, the contract is now in its eighth year. Government personnel were unavailable to provide a DoD perspective, but the finding supports the expectation that PBLs should ideally transition from Cost-Plus to Fixed Price.

Of particular interest are the Cost Plus Incentive Fee (CPIF)-based PBL contracts for the F-117. These contracts, while CPIF, are also Total System Performance Responsibility (TSPR) contracts. The TSPR concept gives the contractor greater responsibility not only over design and engineering, but operational support as well (Loudin, 2010; White, 2001). A criticism of TSPR from the Air Force's perspective is their "must pay" nature (General Accounting Office [GAO], 2000, p. 12). TSPR contracts call for stabilized funding, requiring the government to obligate funds at the beginning of each year. While this was beneficial to the contractor, many within the Air Force considered it a mistake—the clause essentially created a bill that had to be paid in full even if operational requirements changed the use and/or amount of funding directed towards a TSPR program, making other programs without similar arrangements absorb cuts (GAO, 2000). However, in the instance of the F-117, Lockheed Martin used this stabilized funding to successfully reduce costs over the long run, and when the follow-on contract was created, it continued in the same manner (Hunter, 2000). The must-pay bill issue is still prominent in PBL contract structure discussions using WCF, and the arguments and suggested solutions concerning this issue are further discussed in the results for investigative question No. 4.

Question 2: What risks and other criteria most frequently play a role in determining PBL contract type and length?

Responses pertaining to this investigative question varied greatly, which created difficulties in conclusively identifying which criteria have the greatest influence. Table 4 lists all of the issues that interviewees cited as either having influenced contract structure or having the potential to influence contract structure.

TABLE 4. FACTORS THAT INFLUENCE PBL CONTRACT TYPE AND LENGTH		
Factors for Government	Factors for Contractors	Factors for Both
<ul style="list-style-type: none">• DoD budgeting process—significant changes in operations may need to be addressed annually• Precedents set by past PBL programs• May need to rely on Original Equipment Manufacturer because there are no organic support options• Best value of cost vs. performance	<ul style="list-style-type: none">• Risk of underbidding and getting stuck with an unprofitable contract• Reputations at stake—performance may be more important than short-term profitability in order to earn future business• Setting up a support infrastructure (personnel & installations) requires significant investment• General risks:<ul style="list-style-type: none">◦ System reliability trends◦ Obsolescence◦ Program stability◦ Profit margins◦ Inflation◦ Overall relationship with customer	<ul style="list-style-type: none">• Newness of program/contract (are requirements/costs clear?)• Lack of historical data for system• Risks associated with rapid changes in environment and material costs• Risks associated with accuracy of demand forecast• Contract length can be an enabler for affordability improvements• Cash-rich contractors can afford to take risks when government funding doesn't come through as expected

Question 3: In general, are contracts adequately structured to consistently meet the PBL goal of establishing long-term partnerships?

By and large, case study interview participants classified their associated programs as long-term partnerships and had positive views of the programs in this regard. Participants from both sides acknowledged the need to make commitments and share both risks and rewards.

Question 4: In general, are PBL contracts adequately structured to consistently provide incentives for contractors to make cost-reducing investments in system support?

Interviewees expressed a wide range of views concerning individual contracts' levels of effectiveness in meeting these PBL goals. The satisfaction with investment incentives was highest among programs that had multiple guaranteed contract years or guaranteed funding. Suppliers with shorter or less guaranteed contracts expressed that investment incentives were lacking. In most cases, ROI did not seem to be a significant issue because defense contractors will rarely enter into contracts with the government that are unprofitable, even if they are not as lucrative as would be preferred.

One SME expressed his belief that while the government has done a good job of incentivizing performance in the short term, it has not found a way to truly incentivize cost reduction over time.

One significant comment was offered by a representative for a major program who suggested that the two biggest enablers for vendors to accomplish weapon systems affordability improvements are long-term contracts and price-based (vs. cost-based) contracts. This would suggest that it is in the government's best interest to work towards long-term, Fixed Price PBL contracts whenever possible.

Another contract incentive that has not been traditionally implemented, but has potential to result in greater affordability improvements is the concept of *profit sharing*. The government has recognized efficiencies achieved by contractors as opportunities to both lower costs and attempt to negotiate a lower price whenever possible. This tends to limit creativity and incentive for investment on the contractor's part because the government is the only party that enjoys the increased ROI. One SME expressed his belief that while the government has done a good job of incentivizing performance in the short term, it has not found a way to truly incentivize cost reduction over time. Profit sharing may be the key to solving this problem.

Question 5: In general, how satisfied are PBL experts in both DoD and private industry with the government's application of risk aversion in PBL contracts?

Assessments of the government's risk aversion in PBL varied significantly among SME interview participants at the DoD level; while some government representatives thought risks had been appropriately addressed on both sides, others (both government and industry) felt the government was too risk-averse and that risk sharing had been ineffective. The majority expressed dissatisfaction with the government's risk aversion in PBL contracts. One industry executive claimed that "virtually all PBLs are successfully achieving their objectives and saving life-cycle costs for the government, and the process for performing business case analysis as a precursor for award is torturous." He suggested that the DoD's risk aversion has kept PBL from becoming a more prevalent contracting strategy. Another senior industry representative suggested that there is not enough due diligence in government to fully understand the risk profiles that contractors are taking on, noting it is worth understanding because sometimes the contractor isn't taking on much risk.

Several results from interviews conducted at the program level were applicable to the topic of risk aversion. There was considerable acknowledgment from both DoD and industry that risks must be shared for PBL contracts to be effective. Notably, this was mentioned repeatedly as a success factor for two of the high satisfaction programs. In contrast, an industry representative for another program felt that while risk sharing was sufficient in the early years of the contract, the government was now showing a little too much risk aversion in its reluctance to give serious consideration to a Fixed Price contract. Risk is best summarized by one industry representative who commented that crafting a PBL contract is "really all about risk sharing."

Question 6: Would any significant benefits be gained if the maximum contract length allowed by the FAR were increased?

In the cases under consideration, of the eight individuals who were asked whether or not FAR limitations had affected program contract lengths, five indicated that the FAR was irrelevant. Two of the respondents who believed the FAR had limited contract length were associated with a program that was classified as a service and thus was prevented by the FAR from attaining the desired "5+5" structure (5 years plus five 1-year options). For further discussion on these limitations, see Edwards (2003).

Several SMEs asserted that their on-the-job experience yielded little evidence to suggest any real need to change the contract length limitations in the FAR; PBL goals can and are being accomplished using initial base contracts of 5 years or less. One private industry authority expressed that the FAR limitations are indeed relevant, but not as important as the funding limitations associated with the 1-year operations and maintenance (O&M) money that is used to fund major PBL efforts.

The Emerging Problem

A recurring finding throughout the research was that the real issue was not the limitation on the number of base years for a PBL contract, but a lack of guaranteed funding during those years. This seems to represent what industry wants most out of PBL deals, but it is something the government can't truly provide using current practices. The concept of PBL says that a longer contract is better, but reality dictates that funding will only be approved annually, and this limits implementers' ability to get the full potential out of PBL. Clearly, most defense contractors seek to achieve FFP contracts that are guaranteed over several years. The government also benefits from FFP contracts, but struggles to guarantee them for longer than a year at a time because military requirements can change rapidly, and Congress reacts with annual changes to the defense budget. Unfortunately, Congress is not likely to change its funding methods in the near future, so PBL contract builders can expect to continue to face the challenge of creating long-term deals with fiscal uncertainty.

Question 7: Are award term and option year contracting strategies being used effectively, and should their use continue in a lesser, similar, or greater capacity?

Award terms create an obligation for the government to extend a contract if the specified conditions are met, whereas option years give the government the choice to extend regardless of performance. This study found that while most programs have used option years, only Air Force contracts seem to have used award terms. While the distinction does exist in practice, it seems to be a distinction without a difference. Despite the fact that award terms (and options) are not guaranteed, it was found that they provide incentives to contractors to perform well in the long run. One SME asserted that award terms can be effective because keeping business is a very strong incentive; once a revenue stream is established, firms don't want to lose it. A DoD SME believed that while the award term can be an effective tool, it "needs to be tied to better cost-reduction incentives."

This research uncovered no instances in which award terms/option years were needed to provide the government with a way out of a PBL deal gone bad.

Guidance for PBLs consistently points to award terms and option years as off ramps for the government in big PBL contracts, giving the government a way out if the contractor is failing to meet performance standards or price. Obviously, contractor performance is central to the decision to continue a PBL contract. This research uncovered no instances in which award terms/option years were needed to provide the government with a way out of a PBL deal gone bad. Interestingly, even among the examples given, the reasons for contract termination did not include bad performance on the part of the contractor.

Question 8: Should WCF be used more extensively in PBL programs across DoD?

According to those interviewed in the case study, WCF have been used to fund supply support for PBL programs in various parts of DoD—most extensively by the Navy. When applied, WCF have successfully allowed longer PBL contracts; however, they have restrictions on where they can be used and therefore do not seem to be recognized as a widespread strategy for lengthening contracts.

Most SMEs agreed that WCF are best suited for use at the subsystem or component level. An Air Force interview participant assessed that the Navy has made the use of PBL more straightforward by cordoning off some WCF money to be used on PBLs classified as supply contracts. He maintained that the Air Force is learning how to use these funds more effectively and that the Air Force WCF will be used in more PBLs in the near future, especially with proposals such as the fenced funding described under investigative question No. 6. Most experts expressed a belief that the Air Force and Army have room for improvement in the use of WCF for PBL, and that the Air Force has taken steps in that direction (no assessment of the Army was provided). The research did not reveal the utilization of WCF to be at the heart of PBL

contract structure issues, however. Most expressed the belief that questions about what is achievable and affordable, and which contracting approach is best suited to the task were of greater importance.

Question 9: Does a PBL agreement's place among the Four Stages of PBL have any impact on contract length decisions?

This research found little evidence to suggest that any direct link exists between contract length and where a PBL fits within the Four Stages. The DoD SMEs interviewed did not believe that the Four Stages had much impact on contract decisions. One stated that the "Four Stages don't properly express what's being done" in PBL, and another pointed out that because "there is little real benefit from PBL in the short term," PBL should address long-term sharing of risks and costs regardless of the level at which it is implemented.

One industry SME believed that programs entailing higher levels of complexity, such as platform-level responsibility, require more long-term commitment, while material management support contracts that require little to no investment do not need to be long term. This suggests that the length of commitment from both parties in a PBL agreement should increase in proportion with the stages of implementation. While this is a logical assumption, PBL contracting behavior does not necessarily support it. Supply support contracts enacted at the Stage 1 or 2 level are not only typically less risky than Stage 3 contracts, but can also usually draw income from WCF, which allows for longer contracts. A general consensus among those interviewed was that no Stage 4 PBL has ever truly been implemented.

The most interesting finding repeated by most interviewed is that the Four Stages concept is misperceived in the acquisition and contracting communities, and that contrary to popular belief, PBLs should not strive to move up to the next stage in this supposed PBL evolution. Stage 4 is often presented as a goal for which all PBL programs should strive. Vitasek et al. (pp. 7–8, 2006) describe the Four Stages model as "a tool for program managers in charting a path to extend their PBL strategies to higher levels and broader scope," but as several interviewees agreed, nothing is inherently wrong with an effective Stage 1 PBL. Higher stage PBLs are difficult to implement, and when a lower stage PBL has been properly implemented, the warfighter is better off as a result. Attempting to move such a program to the next level may not be necessary or achievable.

Conclusions and Recommendations

The conclusions and recommendations are divided into three sections. The first section brings together the research findings and examines how they can be used to answer the overall research question. The second section discusses limitations that were encountered in this research, and the third section puts forward some recommendations for future research and answers the research question:

How can the Department of Defense ideally balance PBL contracts to mitigate operational and financial risks while simultaneously building long-term partnerships that encourage investment from commercial contractors?

This research sought to draw conclusions about how the DoD can achieve the balance depicted in the research question. Ultimately, the findings gleaned from the authors' research revealed five main areas where efforts for improvement should be concentrated:

1. Congressional funding methods are not compatible with PBL.
2. Option years provide flexibility today; flexible performance may be the solution for tomorrow.
3. Improve incentives with increased use of profit sharing.
4. Long-term contracts aren't always the answer...but they usually are.
5. Keep working towards fixed price/price-based contracts.

The DoD simply cannot always guarantee the funding levels that would allow it to commit to long-term contract periods.

Congressional Funding Methods Are Not Compatible with PBL

As discussed previously in this article, the annual allocation of funds (primarily O&M) creates difficulties for implementers of PBL. In fact, the findings of this research suggest that it is the single biggest challenge facing those who seek to craft PBL contracts consisting of multiple guaranteed contract years. The DoD simply cannot always guarantee the funding levels that would allow it to commit to long-term contract periods. Other methods are being explored for funding PBL in such a way that mitigates the risk of budget fluctuations, such as fencing off money within the Services to be used for PBL programs. If significant changes in PBL funding methods were to take place, they could eventually force changes to contract length limitations in the FAR, which currently do not appear to have a widespread impact on PBL contracts. Alternate funding methods for PBL are controversial, however, and it is not reasonable to expect that Congress will alter its O&M funding methods in the near future. Therefore, for now, PBL officials must use other methods to build funding flexibility into contracts, such as option years, award terms, and flexible performance metrics.

Option Years Provide Flexibility Today; Flexible Performance May Be the Solution for Tomorrow

Option years and award terms are typically described as providing the government with off ramps in a PBL contract, giving the government a way out if the contractor is not performing adequately. While contractor performance is important to decisions to extend PBL contracts, this description does not seem to reflect the way option years and award terms are being used. This research failed to find an instance of a PBL program in which the DoD needed a way out due to performance. This finding, combined with the history of the DoD's relationships with major defense contractors, suggests that the risk of a contractor underperforming in a PBL arrangement is rather small. Its use then, suggests another rationale: optional contract years provide the government with the flexibility it needs to make adjustments based on budget fluctuations. When option years and award terms are negotiated, the government has the opportunity to make changes to the contract as a response to changes in funding. Therefore, option years/award terms provide one method of building flexibility into PBL contracts.

Considering that the option year and award term concepts were devised with intentions other than those for which they are primarily being employed, it would be wise to explore other



options for making PBL contracts financially flexible over the long run. One suggested alternative is the concept of flexible performance. Utilizing flexible performance metrics, PBL contracts can be written to accommodate unexpected fluctuations in operational requirements and funding, eliminating the government's fear of being penalized for funding reductions that affect a long-term contract. Put simply, flexible performance provisions allow contractors to deliver less performance when the DoD needs to pay them less money. Changes in performance delivered are measurable, meaning that they are directly proportional to changes in funding, and allow program managers in both the public and private sectors to predict how much performance will decline as a result of an anticipated reduction in funds. This is an advantage that typically cannot be found in non-PBL programs, and should be leveraged as a means of allowing longer contracts where they are needed.

Improve Incentives with Increased Use of Profit Sharing

Effective partnerships require the sharing of both risks and rewards. While risk sharing is understood to be at the core of PBL relationships, reward sharing seems to have received less attention. Because the government has historically recognized efficiencies achieved by contractors as opportunities to lower costs (primarily in Cost-Plus situations), contractors have often had little incentive to make creative improvements and investments in sustainment because only the government enjoys the return. In contrast, when contractors improve efficiencies that result in profits in some fixed-price situations, the government may see performance improvements, but not cost reductions. If PBL contracts more frequently included provisions for profit sharing between the DoD and private vendors, benefits may be realized by both parties. Because profit sharing benefits everyone and is conceptually well-suited to the mutually beneficial partnerships that PBL agreements claim to be, it would seem that financial returns on improvements should be shared whenever feasible.

Long-Term Contracts Aren't Always the Answer...But They Usually Are

Because PBLs are tailor-made to fit requirements of different types of programs, it is difficult to make generalizations about ideal contract length. Nonetheless, it cannot be denied that long-term contracts are at the heart of PBL strategy. While no universally agreed-upon definition exists of "long-term" in the PBL context, this research found in practice the term refers to agreements of 5 years or more. PBL programs in the DoD have attained substantial success in the



execution of contracts that consist of 5 base years plus 3 to 5 option years or award terms (Kratz, 2007). This type of contract length has many benefits, including:

- Long-term agreements strengthen the partnership between the DoD and private industry.
- When combined with the right contract type, contractors have more incentive to invest in logistics support for systems, enabling affordability improvements.
- Contractors see opportunity for greater ROI.
- Labor is not expended rewriting the contract from year to year.

Some drawbacks are associated with this contract structure as well, the most prominent of which is the loss of flexibility during the initial guaranteed years to deal with fluctuating budgetary requirements. In some instances, both parties cited the shorter contract as ideal due to unique circumstances. But in general, data indicate that commitment to long-term contracts produces effective performance-based partnerships, and that the government's reliance on original equipment manufacturers for weapon systems sustainment tends to be drawn out over many years. Therefore, whenever possible, PBL implementers should strive for something that resembles a 5+5 contract structure.

Keep Working Towards Fixed Price/Price-Based Contracts

This research supports the notion that whenever possible, PBL implementers should strive to achieve a Fixed Price contract for their programs. The success of programs with some form of Fixed Price demonstrates that this is a meaningful goal. Fixed Price contracts align with the PBL goal of purchasing a defined outcome at a defined price; they stabilize prices for the government while guaranteeing a specific level of revenue for vendors. In turn, this provides incentive for contractors to make affordability improvements to systems because money saved can be turned into profit. (Ways to make these improvements beneficial to both parties are discussed in the following section.) A long-term contract alone does not encourage a supplier to make investments; it must also have provisions that reward such behavior. As one commercial SME put it, "without a fixed price, a long contract only serves to reduce the contracting burden," meaning that less frequent contract revisions are the only notable benefit.

A Fixed Price contract can be difficult to accomplish; data that support a stable price are often difficult to gather and comprehend. If not properly planned for during cost-reimbursable stages of a contract, a Fixed Price contract may never be attained. Therefore, PBL implementers should keep the Fixed Price goal in mind from the inception of a PBL contract, and work towards it over time. Note that some elements of a PBL contract may not be suited for Fixed Price; therefore, the effort to reach a Fixed Price contract should not preclude keeping some elements of a contract in a Cost-Plus state.

Summary, Implications, and Limitations

PBL, while embraced by the DoD as a preferred strategy for weapon systems sustainment, remains a complex, and at times misunderstood, process. Improvements made to the way PBL contracts are structured can have significant impacts. This research addressed the question of how to balance PBL contracts to mitigate operational and financial risks while simultaneously building long-term partnerships that encourage investment from commercial contractors. Findings from the research suggested that improvements can be made in PBL by focusing (when applicable) on the five areas described in the previous paragraphs.

PBL, while embraced by the DoD as a preferred strategy for weapon systems sustainment, remains a complex, and at times misunderstood, process.

This research was constrained by certain limitations; specifically, accessibility of personnel and information limited the number of cases studied and personnel interviewed. Because both the PBL programs studied and the number of experts interviewed were greatly dependent upon the responsiveness of personnel contacted and their willingness to participate, the population in this study is represented by more of a convenience sample than a random sample. Given more time and/or resources, a broader, more

balanced study might provide a greater understanding of the issues, further substantiate the findings of this study, or suggest alternative conclusions not discussed in this study.

The very nature of PBL made it difficult to generalize results across the entire PBL spectrum. As discussed repeatedly, every PBL agreement is tailored to fit unique requirements, and because PBL is not a one-size-fits-all approach, it is difficult to make generalizations that can be applied to all programs. In addition, the different military Services seem to have differing philosophies about how PBL should be approached, and these differences become more complex when the different system levels (i.e., platform, subsystem, etc.) are factored in.

Lastly, the possibility of bias must be assumed: While interview participants attempted to give unbiased assessments of PBL issues, in some cases their opinions may possibly have been skewed by the perspectives of their organizations; that is to say, they may have highlighted what was in their organizations' best interest.

Recommendations for Future Research

A study of effective PBL contract structures and incentives that more clearly delineates between practices at the subsystem/component levels and practices at the platform level could prove beneficial. A comparison of best practices at the different levels could serve to identify whether the recommendations presented in this research should be generalized across all PBLs or whether they are appropriate only at certain levels of system support.

Similarly, a comparison of PBL contracting approaches among the Air Force, Army, and Navy may help to determine whether some contract-building strategies are best suited to specific branches of the military. Such a study could clarify the degree to which the generalizations presented in this research are applicable in each of the armed forces, or perhaps identify areas where the different Services should better align their methods.

Future research may also investigate how the recommendations presented in this study might best be carried out. Of particular interest would be an exploration of potential alternatives for PBL funding methods, or new ways to overcome the barriers that the current budgetary process creates.

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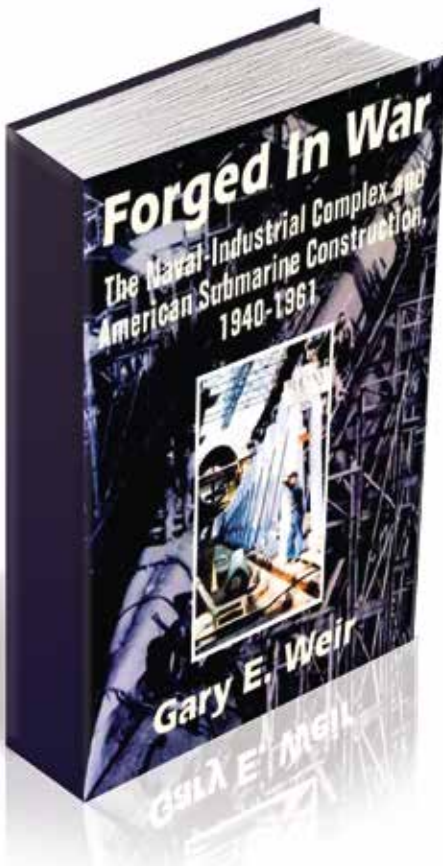


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The Defense Acquisition Professional Reading List is intended to enrich the knowledge and understanding of the civilian, military, contractor, and industrial workforce who participate in the entire defense acquisition enterprise. These book reviews/recommendations are designed to complement the education and training that are vital to developing the essential competencies and skills required of the Defense Acquisition Workforce. Each issue of the *Defense Acquisition Research Journal (ARJ)*

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We encourage *Defense ARJ* readers to submit reviews of books they believe should be required reading for the defense acquisition professional. The reviews should be 400 words or fewer, describe the book and its major ideas, and explain its relevance to defense acquisition. Please send your reviews to the Managing Editor, *Defense Acquisition Research Journal*: DefenseARJ@dau.mil.



Featured Book

Forged in War: The Naval-Industrial Complex and American Submarine Construction, 1940-1961

Author: Gary E. Weir

Publisher: Naval Historical Center

Copyright Date: 1993

Hard/Softcover/Digital:

Softcover, 314 pages, available online at <http://www.amazon.com/Forged-War-Naval-Industrial-Submarine-Construction/dp/0756766400>

Reviewed by: Stafford A. Ward, Department of Defense civilian at the Defense Security Cooperation Agency.

Review:

Gary E. Weir is an accomplished naval historian who has authored several titles on U.S., Russian, and German naval histories. In *Forged in War*, Weir tells a compelling story of how the U.S. Navy, defense contractors, and the scientific community worked together to form a naval-industrial-science complex to support America's entry into World Wars I and II. Reading *Forged in War* is akin to reading the U.S. Navy's history of submarine development and submarine strategic warfare from World War I to the early years of the Cold War. *Forged in War* aptly describes the evolution of the naval-industrial-science complex as a "command technology" of the U.S. Navy, directing and managing the acquisition process for U.S. industry. Weir uses mechanical and aerospace engineering concepts to explain technical details of how the naval-industrial-complex constructed submarines using advanced sonar, propeller, diesel-engine, and later nuclear-engine technologies. *Forged in War* also describes early uses of concepts that defense acquisition professionals currently use on a regular basis such as systems analysis, operations research, and project management methodologies.

Initial collaboration existed between the U.S. Navy's Bureau of Ships (BUSHIPS) and the defense industry to design and develop large warships and submarines to face significant threats from the German Kaiser's navy during World War I. The interwar years saw a dramatic decline in submarine orders from the U.S. Navy as a result of significant defense budget cuts from Congress. However, a decline in submarine orders would be short-lived after Hitler's armies raced across Europe in 1940, which prompted the Chief of Naval Operations and other senior U.S. naval officials to begin establishing the design requirements for defense contractors to once again build submarines to defeat both the German and Japanese war machines. In *Forged in War*, Weir focused exclusively on U.S. submarine and antisubmarine warfare (ASW) strategies against Germany during World War II, and later against the Soviet Union during the Cold War.

The introduction of the Woods Hole Oceanographic Institution and other members of the scientific community into the naval-industrial complex during World War II added an element of expertise that neither the U.S. Navy nor industry could devise on their own. The defense acquisition management system in use by defense acquisition professionals today has its foundations in the "command technologies" of World War II. In addition to the naval shipyards owned by defense contractors, such as the Electric Boat Company (now General Dynamics Electric Boat), BUSHIPS allowed defense contractors to use U.S. Navy-owned shipyards to maintain the high number of submarine orders as a result of the combined efforts of the

naval-industrial-science complex. The U.S. Navy benefitted significantly from German aircraft and naval technologies captured by the U.S. Naval Technical Mission in Europe, a group of special operatives who perilously followed the invading U.S. armed forces into Western Germany. During the early years of the Cold War, naval engineers and the scientific community integrated the captured German technology, which included conning towers; efficient diesel engines; and guided, cruise, and ballistic missiles onto U.S. submarines. These integration practices also reflected a shift from the U.S. Navy's strategic focus from offensive submarine warfare during World War II to defensive ASW during the Cold War.

However, the growing resentment of personalities between the U.S. Navy and defense contractors during the late 1950s severely hampered the positive collaboration of individuals that participated in the naval-industrial-science complex during World War II. In addition, the U.S. Navy began to oppose the technological enhancements suggested by the scientific community for the future of ASW warfare. Although it is beyond the scope of this book, *Forged in War* could have explained for today's defense acquisition professionals how systems analysis and the planning, programming, and budgeting system forever changed the dynamics of the naval-industrial-science complex from World War II to the early years of the Cold War.





Defense ARJ Guidelines FOR CONTRIBUTORS

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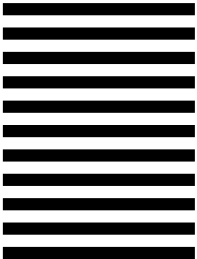
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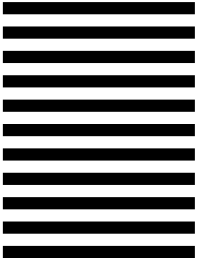
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